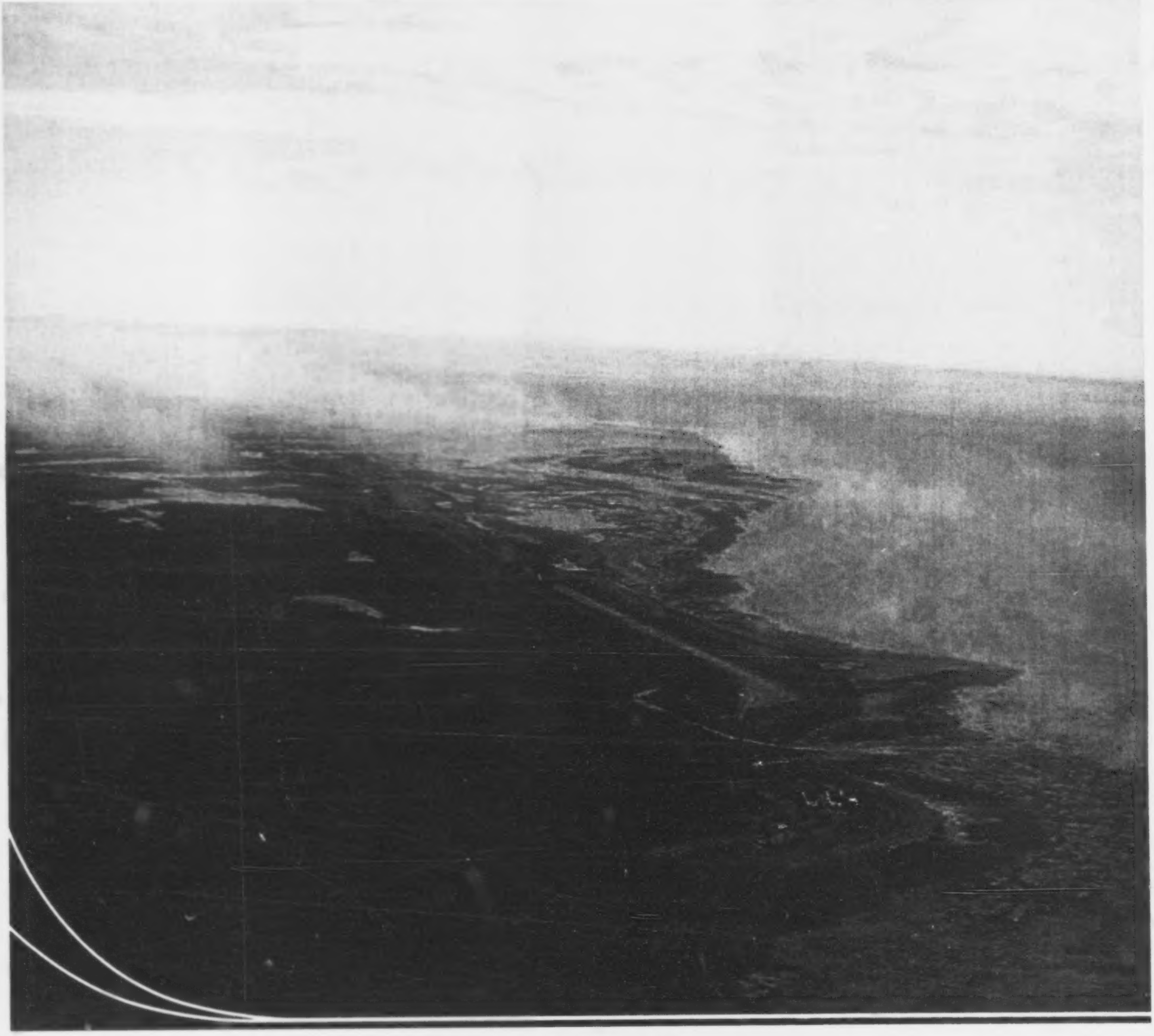
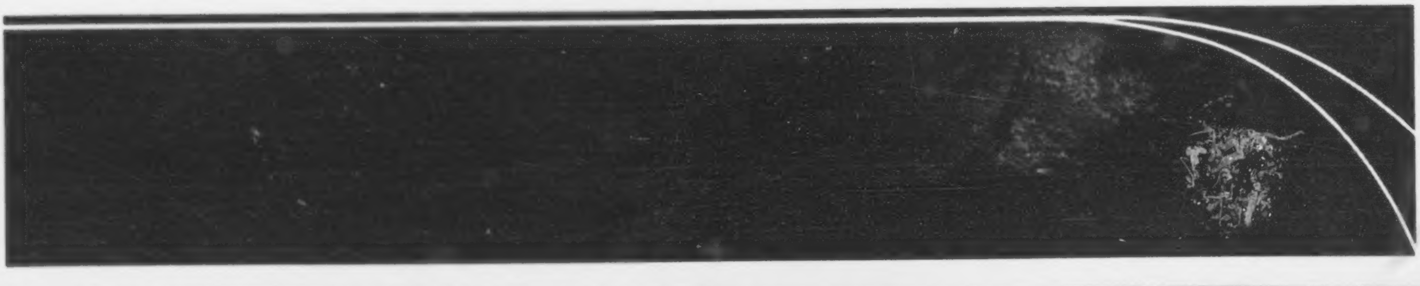


SCIENCE FOR A CHANGING FAR NORTH

The Report of the Far North Science Advisory Panel
April 2010



©2010, Queen's Printer for Ontario,

Printed in Ontario, Canada

Science for a Changing Far North

The Report of the Far North Science Advisory Panel

April 2010

Copies of this report are available at www.ontario.ca/farnorth

This publication should be cited as:

The Far North Science Advisory Panel. 2010. Science for a Changing Far North. The Report of the Far North Science Advisory Panel. A report submitted to the Ontario Ministry of Natural Resources.

ISBN 978-1-4435-3540-3 (Print)

ISBN 978-1-4435-3541-0 (Web)

TABLE OF CONTENTS

i. **Preface** i

ii. **Executive Summary** ix

1.0 **Introduction** 1

- 1.1 The Science Panel 2
  - Terms of Reference 3
- 1.2 Bill 191. The Far North Act (as amended October 22, 2009) 3

2.0 **Ecological Overview** 7

- 2.1 Human History 15
- 2.2 Geology and Climate 16
  - 2.2.1 Geology 16
  - 2.2.2 Climate and Permafrost 18
- 2.3 Hydrology and Water Quality 20
  - 2.3.1 Hydrology 20
  - 2.3.2 Surface Water Quality 22
- 2.4 Peatlands 23
- 2.5 Forests 26
- 2.6 Natural Disturbance Processes 29
- 2.7 Biological Diversity 31
  - 2.7.1 Mammals 31
  - 2.7.2 Birds 32
  - 2.7.3 Fish 34
  - 2.7.4 Species and Spaces of Conservation Concern 35

3.0 **Key Management Issues** 41

- 3.1 Climate Change 42
  - 3.1.1 Projected Impacts of Climate Change on Far North Ecosystems 48
  - 3.1.2 The Case of Fire, Carbon and Climate change 51
  - 3.1.3 Communities: Adapting to Climate Change Impacts 52
- 3.2 Internal Drivers of Change 53
  - 3.2.1 Settlements and Associated Infrastructure Support 53

CONTINUED

3.2.2 Energy Generation and Distribution 53
3.2.3 Transportation and Transmission Corridors: Roads and Other Linear Features 55
3.2.4 Exploration and Development of Geological Resources 58
3.2.5 Forestry 68
3.2.6 Wildlife and Freshwater Fish Harvest 70
3.2.7 Tourism and Non-consumptive Economic Development 71

4.0 Approaches to Land Use Planning 75

4.1 Context 76
4.2 The Need for a Novel Approach 77
4.2.1 The Conservation-Matrix Model 77
4.2.2 Uncertainty and the Need for Adaptive Management 79
4.3 Planning To Protect Ecological Integrity 79
Native Species and Ecosystems Occur at Ecologically Functional Levels 80
Natural Disturbance Regimes Operate to Maintain Biological Diversity 80
Productivity, Decomposition and Nutrient Cycling Operate within Characteristic Limits 80
Ecosystems are Resilient to Change 80
4.4 Adaptive Management and the Science of Sustainability 81
4.5 Strategic Considerations 83
4.5.1 Planning Scale 83
4.5.2 Units for Conservation Planning 83
4.5.3 Connectivity 83
4.5.4 Thresholds of Landscape Change 84
4.5.5 Protected Areas and Land Use 85
4.5.6 Planning for Specific Ecosystems and Species 89
4.5.7 Comprehensive Landscape Management 93

5.0 Recommendations 97

1. Create a Coordinated Governement Wide Strategy for the Management of Interim and Ongoing Development 99
2. Immediately Designate the 'Ring of Fire' as a Priority Management Area with an Interim Sub-Regional Planning Process 99
3. Immediately Establish a Far North Land Use Strategy 100
3.1 Conduct Land Use Planning to Protect Ecological Integrity of of the Region as a Whole 100

CONTINUED

3.2 Mitigate Climate Change by Preventing or Minimizing the Loss of Carbon Storage in Biomass and Soil 100

3.3 Consider the Impacts of Climate Change in Land Use Planning 101

3.4 Establish a Framework for Protecting Areas of Cultural and Ecological Significance 101

3.5 Use Watersheds or Other Natural Boundaries as the Basis for Establishing Protected Areas 102

3.6 Coordinate Planning and Management Across Administrative Boundaries 102

4. Plan Developement Incrementally, in a Considered, Proactive Fashion 103

4.1 Assess and Manage Cumulative Impacts 103

4.2 Maintain the Existing Moratorium on Large-Scale Hydro-electric, Development and Extend it to Include Inter-Basin Water Diversions 103

4.3 Plan Transportation and Transmission Corridors in a Coordinated Fashion, Recognizing Community Needs and Protecting Significant Ecological Features 104

4.4 Prevent the Introduction of Invasive Species 104

5. Apply the Best Continuous Learning Approaches Through Adaptive Management 104

5.1 Base Management Decisions on the Best Available Knowledge, but Regularly Revisit and Revise Strategies as our Knowledge Base Improves 104

5.2 Support Planning and Management with an Appropriate Decision-Support System 105

6. Provide Communities and Governments with the Necessary Resources for Planning and Management 106

6.1 Create a Far North Information System to Facilitate the Use of Best Available Knowledge, Including Aboriginal Traditional Knowledge 106

6.2 Improve the Available Information Base Through a Comprehensive Inventory and Enhanced Monitoring Program 106

Appendix 1: Panel Terms of Reference **108**

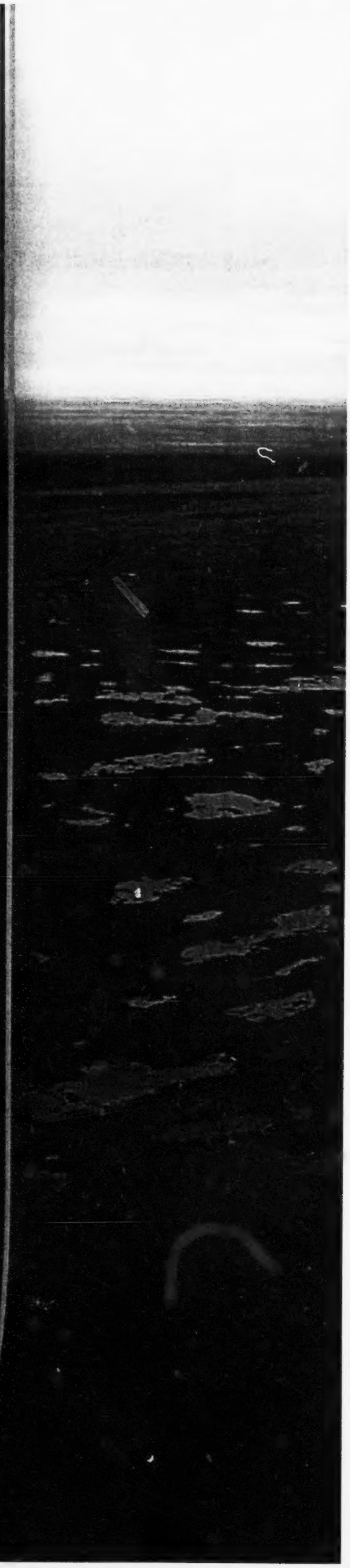
Appendix 2: List of Inventory and Monitoring Needs **109**

Endnotes **112**

PREFACE

For one group it is a frontier, for the other a homeland.

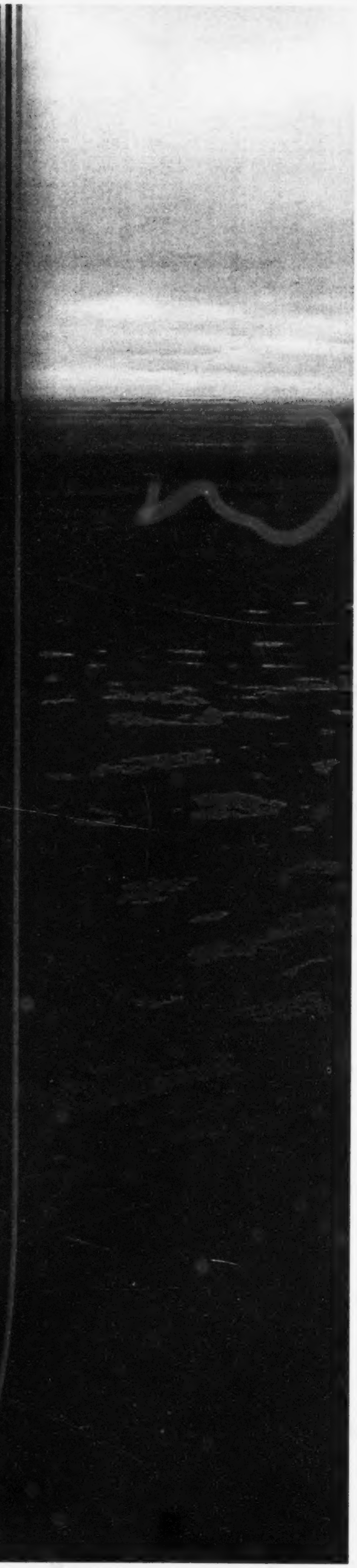
Thomas Berger, 1977



PREFACE

For one group it is a frontier, for the other a homeland.

Thomas Berger, 1977



PREFACE

The Far North of Ontario is one of the world's largest, most intact ecological systems, reflecting a high level of ecological integrity and providing ecosystem services far beyond its borders. It stretches from Hudson Bay south to the boreal forests in Ontario's mid-latitudes, where the land is criss-crossed with roads and towns, and forestry, mines and farms (Fig.1). At 452,000 km^2, the Far North is 42% of the area of Ontario, larger than Newfoundland and Labrador, and 1.5 times the size of Italy, yet very few of Ontario's citizens have any familiarity with it. It is the homeland of citizens whose ancestors have occupied it continuously for millennia. Its 34 communities (Fig. 2) are remote, linked only by short-lived winter roads, air and water, and modern communications. Its residents know the land and they rely on it. They live as close to the land as anyone in North America, on landscapes that are unique and extraordinary (Fig. 3).

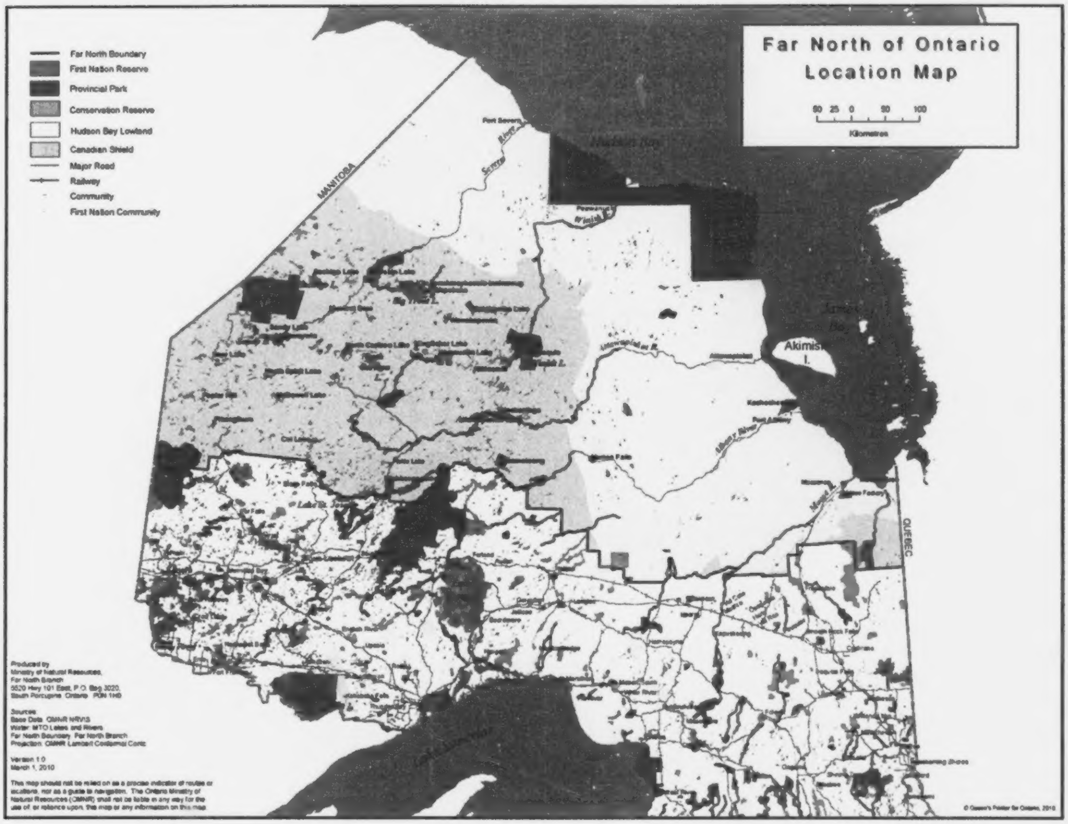


Figure 1. *Far North Location Map. Source: OMNR, 2010.*

In the next few years, the citizens of the Far North will face many choices, some of them involving large-scale developments that will change the region forever. Opportunity and pressure will grow to access and develop the region's mineral, energy and forest resources. Whatever development takes place must improve the quality of life for its citizens and must occur with full respect for the cultural values, natural features and ecological functions that define the Far North. This is the stated intent of new draft provincial legislation regarding the Far North.

The current draft of Ontario's Bill 191, *The Far North Act: An Act with Respect to Land Use Planning and Protection in the Far North*, has four objectives: a significant role for First Nations in land use planning; the protection of its cultural areas and ecological systems within an interconnected network of protected lands and waters; the maintenance of its biological diversity and ecological processes and functions, and the protection of its stored carbon; and sustainable economic development that benefits First Nations.

What is proposed in the legislation is a new kind of decision-making based on the adoption of community based land use plans developed by First Nations in partnership with government, before major development occurs. These plans are also required to take into account broader-scale considerations, including a Far

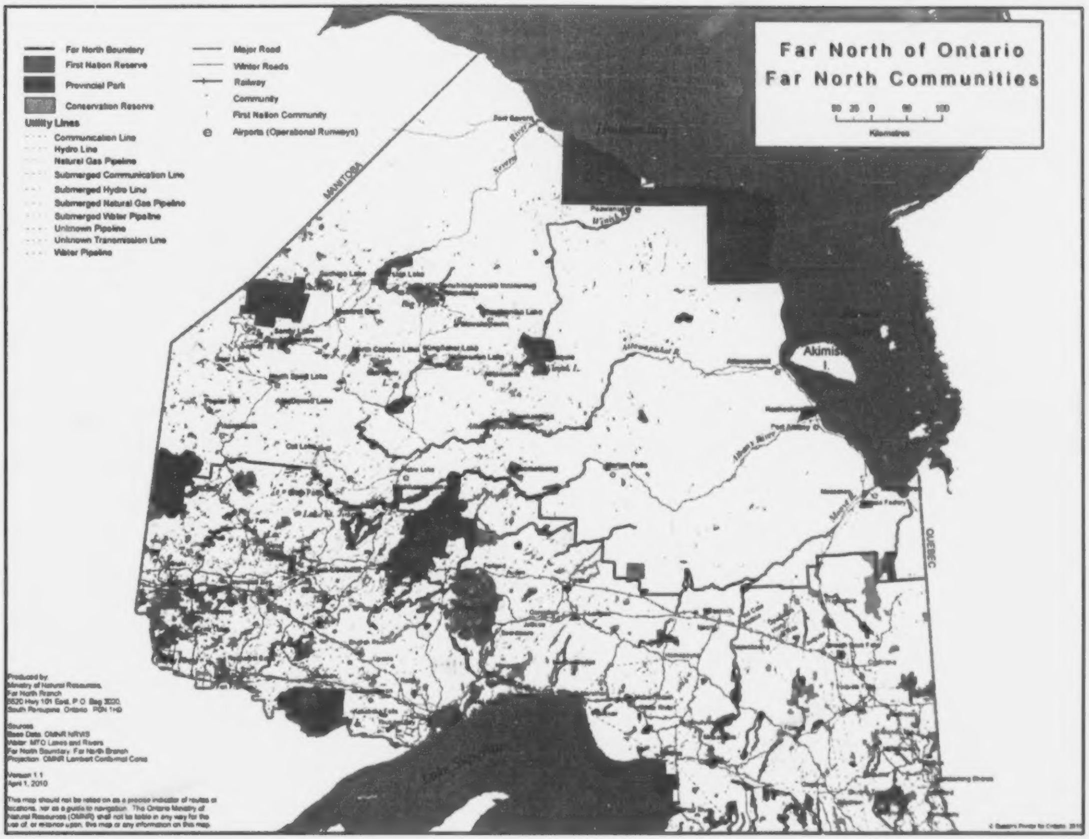


Figure 2. *Far North Communities. Source: OMNR, 2010.*

North Land Use Strategy. *The Far North Science Advisory Panel* was asked to provide advice on that broad-scale strategy. This report provides our advice, and describes the scope and scale of knowledge and awareness – both broad-scale and local – that will be needed if these ambitious objectives are to be met. The residents of the Far North have previous experience with planning, consultation and development proposals. In 1977, Ontario mandated the *Royal Commission on the Northern Environment* to inquire into *"any beneficial and adverse effects on the environment...of any public or private enterprise"* north of the 50° latitude. E.P. Hartt and J.E.J. Fahlgren were its Commissioners, and released an Issues Report (1978) and *An Atlas of Far Northern Ontario* (1985). The inquiry was in response to a proposal for large-scale timber harvest.

The Commissioners met with communities across northern Ontario, including three communities in the Far North, Moose Factory, Moosonee and Mishkeegogamang, as well as in Toronto. The majority of submissions were on social, economic and cultural matters, and Hartt recommended *"the development of an orientation away from centralized forms of social control and decision-making into experimentation with ones that are decentralized and community oriented."* The focus of the Commission was the means by which engagement and mutual benefit could be achieved. *"The process by which change can be introduced*

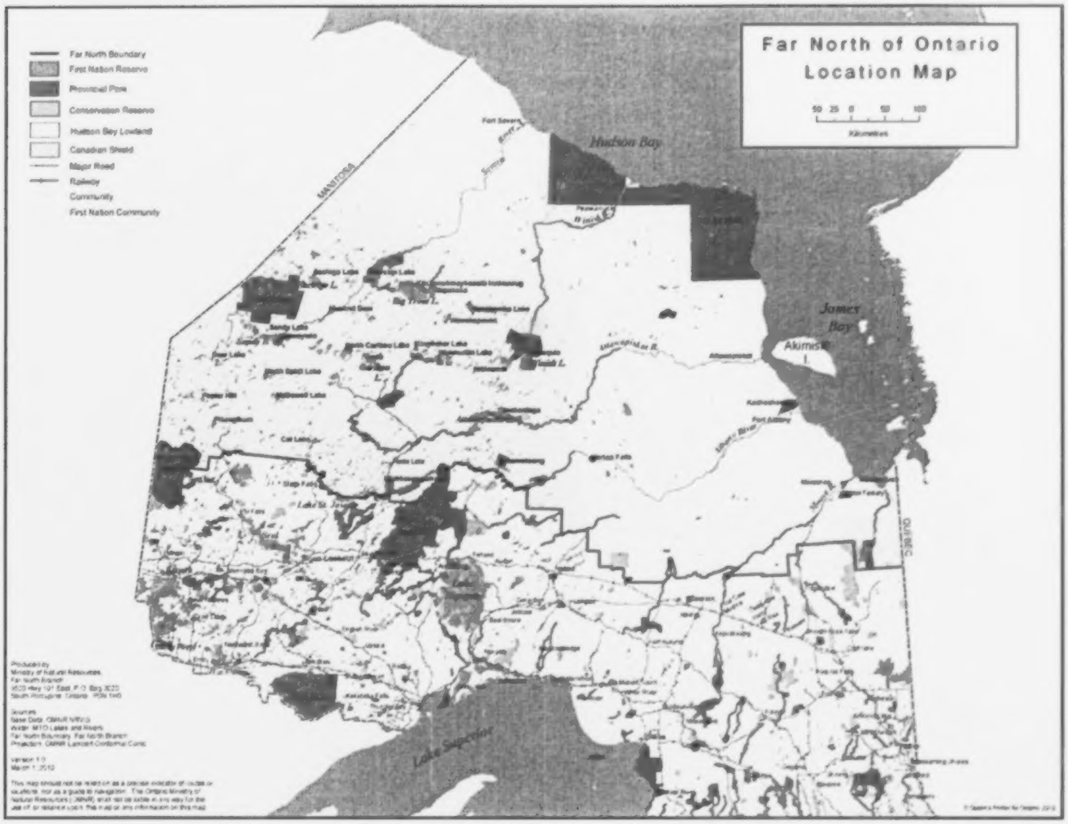


Figure 1. *Far North Location Map. Source: OMNR, 2010.*

In the next few years, the citizens of the Far North will face many choices, some of them involving large-scale developments that will change the region forever. Opportunity and pressure will grow to access and develop the region's mineral, energy and forest resources. Whatever development takes place must improve the quality of life for its citizens and must occur with full respect for the cultural values, natural features and ecological functions that define the Far North. This is the stated intent of new draft provincial legislation regarding the Far North.

The current draft of Ontario's Bill 191, *The Far North Act: An Act with Respect to Land Use Planning and Protection in the Far North*, has four objectives: a significant role for First Nations in land use planning; the protection of its cultural areas and ecological systems within an interconnected network of protected lands and waters; the maintenance of its biological diversity and ecological processes and functions, and the protection of its stored carbon; and sustainable economic development that benefits First Nations.

What is proposed in the legislation is a new kind of decision-making based on the adoption of community based land use plans developed by First Nations in partnership with government, before major development occurs. These plans are also required to take into account broader-scale considerations, including a Far

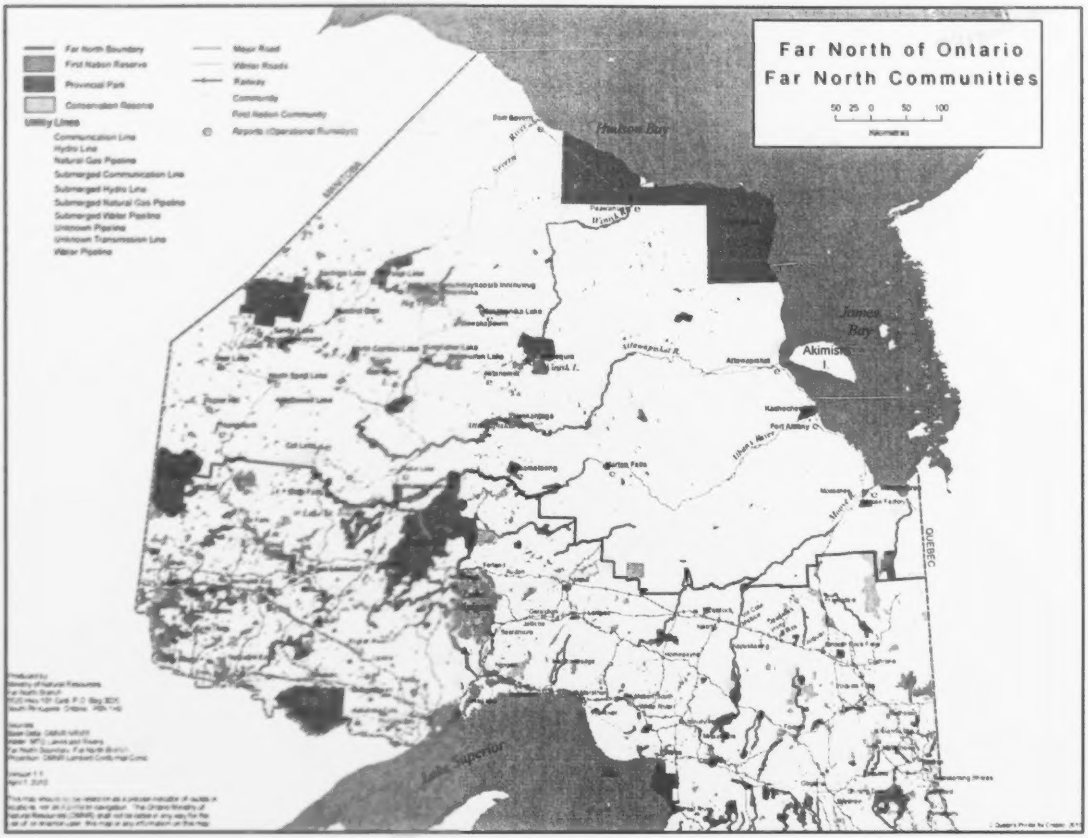


Figure 2. *Far North Communities. Source: OMNR, 2010.*

North Land Use Strategy. *The Far North Science Advisory Panel* was asked to provide advice on that broad-scale strategy. This report provides our advice, and describes the scope and scale of knowledge and awareness – both broad-scale and local – that will be needed if these ambitious objectives are to be met. The residents of the Far North have previous experience with planning, consultation and development proposals. In 1977, Ontario mandated the *Royal Commission on the Northern Environment* to inquire into *"any beneficial and adverse effects on the environment...of any public or private enterprise"* north of the 50° latitude. E.P. Hartt and J.E.J. Fahlgren were its Commissioners, and released an Issues Report (1978) and *An Atlas of Far Northern Ontario* (1985). The inquiry was in response to a proposal for large-scale timber harvest.

The Commissioners met with communities across northern Ontario, including three communities in the Far North, Moose Factory, Moosonee and Mishkeegogamang, as well as in Toronto. The majority of submissions were on social, economic and cultural matters, and Hartt recommended *"the development of an orientation away from centralized forms of social control and decision-making into experimentation with ones that are decentralized and community oriented."* The focus of the Commission was the means by which engagement and mutual benefit could be achieved. *"The process by which change can be introduced*

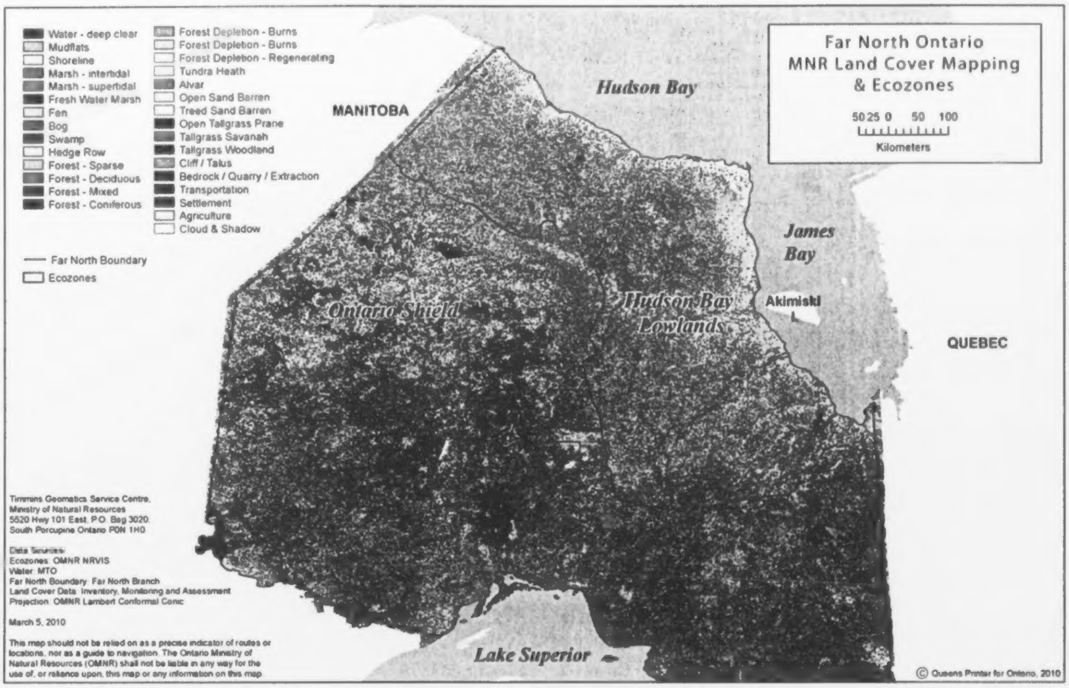


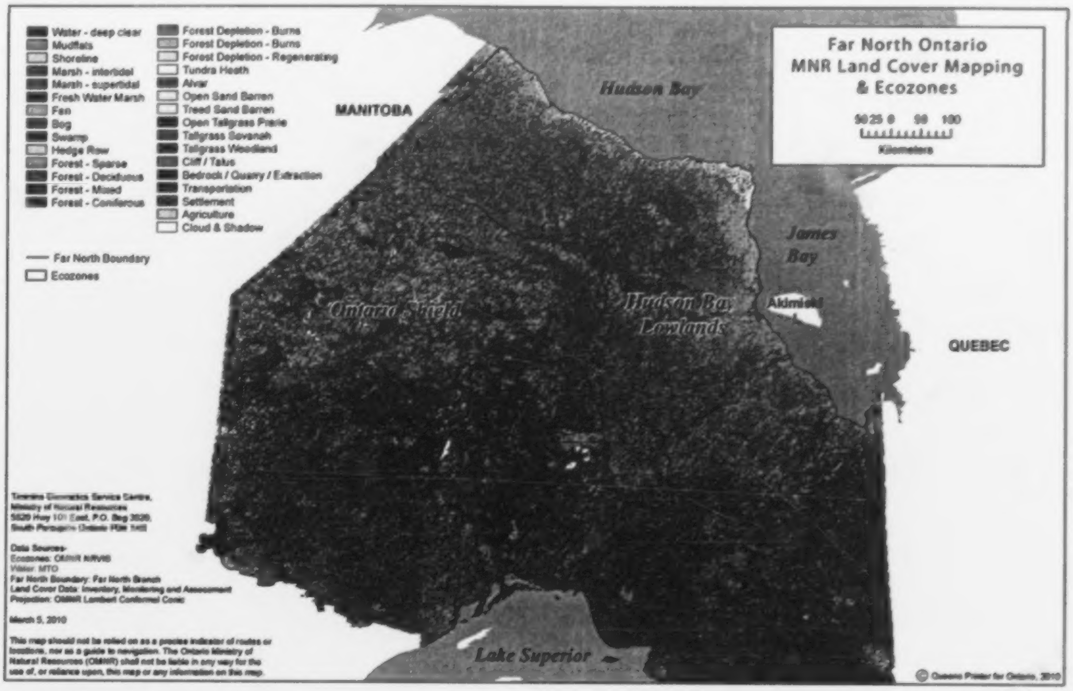
Figure 3. *Far North Land Cover Mapping & Ecozones. Source: OMNR, 2010.*

constructively on all social, economic and cultural questions is by involving northerners in the decisions which will affect their lives."

Commissioner Fahlgren focused on the compilation of information that had been unavailable before. He emphasized the benefits of such information to environmental assessments of developments in the north. He wrote, *"The public is now increasingly insistent that decisions to allow any major proposed project to be implemented be withheld until the likely beneficial and adverse consequences of the project and alternatives to it have been evaluated from social, economic and natural environmental viewpoints."*

As a result, timber was accessed north of 50° but the region north of about 51° remained largely roadless and without large-scale development. Plans by Ontario Hydro in 1989-92 included hydro development of the Abitibi, Mattagami and Moose rivers, but excluded large-scale sites on the Albany, Winisk and Attawapiskat, based on an environmental assessment of economic, social and ecological factors, and First Nation concerns about flooding. The Northern Rivers Commitment with First Nations now prohibits hydro-electric development exceeding 25MW on these rivers and the Severn River.

Broad-scale plans were developed by public agencies; for example, in the 1980s, the public lands of Ontario were the subject of land use planning that resulted in draft plans for the Far North. This was repeated in the 1990s for central Ontario, after which the 2002 Room to Grow report of the Ontario Forest Accord Advisory Board made a commitment that development in the Far North would be *"orderly development"*. The Report stated: *"First Nations [are interested] in commercial forestry potential north of the 51st parallel...*



Timmins Geomatics Service Centre,
Ministry of Natural Resources
5520 Hwy 101 East, P.O. Bag 3020,
South Porcupine Ontario P0N 1H0

Data Sources-
Ecozones: OMNR NRVIS
Water: MTO
Far North Boundary: Far North Branch
Land Cover Data: Inventory, Monitoring and Assessment
Projection: OMNR Lambert Conformal Conic

March 5, 2010

This map should not be relied on as a precise indicator of routes or locations, nor as a guide to navigation. The Ontario Ministry of Natural Resources (OMNR) shall not be liable in any way for the use of, or reliance upon, this map or any information on this map.

© Queens Printer for Ontario, 2010

Figure 3. *Far North Land Cover Mapping & Ecozones. Source: OMNR, 2010.*

constructively on all social, economic and cultural questions is by involving northerners in the decisions which will affect their lives."

Commissioner Fahlgren focused on the compilation of information that had been unavailable before. He emphasized the benefits of such information to environmental assessments of developments in the north. He wrote, *"The public is now increasingly insistent that decisions to allow any major proposed project to be implemented be withheld until the likely beneficial and adverse consequences of the project and alternatives to it have been evaluated from social, economic and natural environmental viewpoints."*

As a result, timber was accessed north of 50° but the region north of about 51° remained largely roadless and without large-scale development. Plans by Ontario Hydro in 1989-92 included hydro development of the Abitibi, Mattagami and Moose rivers, but excluded large-scale sites on the Albany, Winisk and Attawapiskat, based on an environmental assessment of economic, social and ecological factors, and First Nation concerns about flooding. The Northern Rivers Commitment with First Nations now prohibits hydro-electric development exceeding 25MW on these rivers and the Severn River.

Broad-scale plans were developed by public agencies; for example, in the 1980s, the public lands of Ontario were the subject of land use planning that resulted in draft plans for the Far North. This was repeated in the 1990s for central Ontario, after which the 2002 Room to Grow report of the Ontario Forest Accord Advisory Board made a commitment that development in the Far North would be *"orderly development"*. The Report stated: *"First Nations [are interested] in commercial forestry potential north of the 51st parallel...*

MNR is currently working with several First Nations under what is called the Northern Boreal Initiative. The preparation of land use direction and new environmental assessment coverage for forestry in the north will be significant tasks. A new approach called Community Based Land Use Planning is currently being developed. The First Nation communities will lead planning, with MNR's support and assistance."

The *Room to Grow* report also set out a goal of identifying appropriate conservation lands through community plans, before large-scale developments were initiated. On this basis, a community based land use plan by the Pikangikum First Nation for the Whitefeather Forest was completed in 2006, and other such plans are under consideration by other First Nations.

The Far North, with the exception of two active mines, has no major industrial development at present. The draft Ontario Power System Plan (2007), however, includes plans to generate and transmit significant new hydro-electricity from the Far North. Significant new mining, processing and shipping is being promoted in the Ring of Fire mineral field north of the Attawapiskat River. At the same time, however, Ontario has adopted a *Biodiversity Strategy* (2005), and new legislation in support of *Endangered Species* (2007). These documents, along with the *Northern Boreal Initiative*, require the Province and its residents to consider the environmental implications of development, including that in the Far North.

Our report focuses on the value and importance of the environmental features and ecological functions of the Far North, and on the critical science issues we believe deserve close attention in land use planning, environmental assessment, and adaptive management as the Far North changes.

We were not asked to look at the processes through which communities will be engaged in planning and decision-making. Instead we have attempted to answer questions such as: What is known of the global, national and provincial significance of this region? What is its special character that deserves particular attention and protection? What has been learned elsewhere that should guide planning in the Far North? What changes might be driven by a changing climate? We have made specific recommendations about the science-related aspects of land use planning, and the values, principles and adaptive processes the Panel believes should underlie that planning.

Members of the Panel have referred to many reports and studies included in the extensive "Endnotes". Our intention has been to integrate and provide a more general discussion of matters that are in some cases dealt with in more detail elsewhere. At the same time we recognize that the knowledge we have brought to our discussions has not included traditional aboriginal knowledge. We have emphasized that such knowledge should be included when decisions are made in the future.

We have attempted to organize our report and our recommendations in ways that are useful to all planning partners in the development of community based land use plans and also, if need be, in designing interim measures when development is proposed in advance of a community based plan.

In summary, we have focused on the *"beneficial and adverse effects"* of development on communities through the consequences for the environment. We believe our report complements the treatment of community well-being through the *"social, economic and cultural questions"* that were the focus of the *Royal Commission on the Northern Environment* more than thirty years ago.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

This report describes the vast and largely intact ecological systems of the Far North, and recommends a conservation-matrix approach for land use planning. It recommends landscape-level planning, with "benchmark" areas and specific features of interest set aside from development, while other areas are designated for active management, and the landscape overall is planned for continuity and resilience of ecological function. Adaptive management provides a means of evaluating management strategies as climate change and economic development proceed. It will require sustained commitment to the collection and sharing of information about the Far North, including scientific and aboriginal traditional knowledge.

Overview

The Far North of Ontario is one of the world's largest, most intact ecological systems, reflecting a high level of ecological integrity and providing ecosystem services far beyond its borders. It is the homeland of citizens whose ancestors have occupied it continuously for millennia. They know the land, and they rely on it. Their 34 communities are remote, linked by air, water, winter roads, and modern communications. The citizens of the Far North are already involved in making choices about large-scale developments that will change the region forever. This trend is already apparent in regions such as the Ring of Fire, and will only accelerate over the next few years. Change will come first in the form of intense interest in accessing and developing the region's mineral, energy and forest resources. This can only occur with full respect for the cultural values, natural features and ecological functions that define the Far North, and in the context of enabling development that benefits First Nations. These are the stated objectives of new draft provincial legislation regarding the Far North.

A group of scientists, the *Far North Science Advisory Panel*, was asked by the Province of Ontario to consider the state of scientific knowledge about the Far North, and provide scientific advice relevant to land use planning decisions in that region in support of community based land use planning (see Terms of Reference, Appendix A). This report provides that advice.

The Biophysical Environment of the Far North

Large intact landscapes like the Far North are rare. In a global context, the Hudson Bay Lowland of the Far North contains one of the Earth's largest peatland complexes. In the "Boreal Shield"[1*] region to the south and west lies the core of the largest single extant block of boreal forest free from large-scale anthropogenic disturbance anywhere in the world. These peatland and forest systems constitute globally important stores of carbon, mediate ecosystem hydrology, and modify local and regional climates. They are interconnected through the movement of water, air, and organisms, among them federally and provincially-listed endangered and threatened species, and other species of concern.

Most of the region's lakes and rivers are free from the effects of human activity, although some rivers have been developed for hydro-electric power and diversion of flows to the south and west. Water quality is thought to be unimpaired throughout the region, although the drinking water in some First Nations communities has been degraded by poor sanitation, with tragic consequences.

Diesel-based generation of electricity and traffic over winter roads create localized sources of air and water pollution from spilled fuels in First Nations communities. Generally speaking, however, pollution from industrial effluents is currently limited to a small number of mining and exploration sites. Long-range airborne transport and deposition of mercury and persistent organic pollutants such as polychlorinated biphenyls, brominated organic compounds including flame retardants, and pesticides to surface waters is, however, a growing concern, because of the toxic effects caused by accumulation of such substances in fish, wildlife and human tissues. Levels of some of these chemicals are already high in Far North fish – in some cases, at or above the level recommended for human consumption. There is very little margin of safety for additional pollutant inputs.

The region remains a stronghold for biodiversity, including mammals such as caribou, wolverine, Canada lynx, gray wolf, marten, and polar bear, that have suffered declines elsewhere in their ranges, including southern Ontario. Ten of Ontario's mammal species only occur in the Far North, most of them restricted to the Hudson Bay Lowland, and a suite of maritime mammals range along the coast and in river estuaries. The region is also of global importance for migratory birds. For many migrating shorebirds and waterfowl, the shores and associated mudflats of James Bay and Hudson Bay are the only tidal saltwater habitats that are located between the maritime arctic to the north and the Gulf of St. Lawrence, Atlantic Ocean and Gulf of Mexico to the south. In particular, the migratory corridor along the Hudson Bay and James Bay coasts is of global significance for waterfowl and shorebird breeding and migration. The funnelling effect of the coastlines of Hudson Bay and James Bay, which concentrates bird numbers spectacularly during fall migration, is one of North America's few remaining examples of its former faunal abundance. Alteration of these habitats therefore has implications for biodiversity, not only locally but also at the continental and global scale.

At least 50 species of fish are currently known in the Far North, making it a biodiversity "hot spot" for fish in Canada. Common species on the Shield are walleye, whitefish, sucker and northern pike, while species like brook trout and lake sturgeon (a species of special concern) are more common in the Hudson Bay Lowland. Three species or forms (sea-run brook trout, arctic char and fourhorn sculpin) are restricted in Ontario to the Far North. Non-native fish are almost absent; exceptions are smallmouth bass and rainbow smelt, which were brought into a few lakes and rivers in recent decades. Most of the fishing in the Far North is for subsistence, and is localized around communities. Tourism fishing is however the main focus of more than a dozen major base lodges and more than 150 fly-in camps, with very few of them operated by residents of the region.

[1*] *The terms "Boreal Shield", "Canadian Shield", and "Ontario Shield" are often used interchangeably for the portions of the Shield that occur within Ontario. For the purposes of this report, we will use the term "Boreal Shield" or simply "Shield" to refer to the part of the Shield that lies within the Far North, and "Canadian Shield" more generally.*

The remoteness of the Far North and its low level of development also present challenges. Basic biophysical survey and inventory work has only just begun in most areas with, as yet, little understanding of fundamental relationships between species and ecosystems, and the potential for disturbance to alter those relationships. Traditional knowledge would help to address this need, but it is not yet expressed as a region-wide knowledge base. Future conditions are also uncertain, because of the dynamic nature of natural disturbance regimes like fire in the region, the looming spectre of climate change, and the manner and extent to which the region's globally-important mineral resources will be developed.

More Change is Coming

Climate change models and established trends indicate that by the middle of this century, the Far North will likely be considerably warmer and will receive slightly more precipitation than it does today. In spite of the slight rise in precipitation, these conditions will increase the potential for evapotranspiration, and in turn may lead to reductions in soil moisture, lake levels and river flow. Models indicate that some of the most dramatic changes will occur in the most northern extent of the Far North, near the coast of Hudson and James bays. A considerably shorter ice cover season on Hudson Bay and James Bay would lead to much warmer and longer duration summers, and warmer and shorter winters. This, in turn, would lead to the loss of permafrost, changing the surface hydrology and local topography.

The plants and animals of this region are well-adapted to its current extreme climate conditions, so as climate change progresses, it is likely that ecosystem structures will exhibit profound changes. Changes in the amount and seasonal distribution of precipitation will alter the winter versus summer regime of lakes, rivers, and streams, with potentially significant effects on a variety of species. Greater winter precipitation combined with earlier spring melt may lead to larger and earlier spring stream flows. The extent and duration of wildfires are predicted to increase, as air temperature rise and soils and peatlands dry. Changes in species composition should also be expected as species' ranges expand or contract in a warmer climate. Future assemblages of plants and animals may look quite different from current systems.

Even without significant changes in ecosystem structure, however, a warming climate may alter ecological processes in fundamental ways, for example through faster rates of photosynthesis, autotrophic respiration and changes in net primary production. This, in turn, could have a profound effect on ecosystem carbon biogeochemistry and carbon storage. Raising or lowering water levels, whether through climate warming or through human activities such as the building of dams or diversion structures, or carelessly designed road networks, can result in release of potentially harmful materials to downstream waters and to the air.

At present, the human footprint on these vast landscapes is very modest, limited to remote human communities and a handful of industrial developments. Pressure to develop the energy, mineral, and natural resources of the region is growing, however, both from interests in the south and from the communities themselves; there is also great interest in improving access through a network of all-season roads. Community based land use planning, as recommended in the report of the 1977 *Royal Commission on the Northern Environment* and more recently in Bill 191, offers a means for communities to make simultaneous decisions about development and conservation. In particular, the Ring of Fire – McFauld's Lake area appears to have very significant mineral resources, which should have economic benefits for First Nations communities and all of Ontario. Increasing knowledge of the geology along with mineral exploration, especially in the Shield area, indicates the likelihood of new discoveries, possibly related to large scale patterns in the geological structure of the Far North.

Planning for development must be approached with great caution. Individual development projects such as mines, wind energy farms, hydro-electric power and tourism operations have the potential to affect local ecosystem integrity, through habitat alteration, changes in water levels, increased erosion, and release of pollutants to air and water. More significantly, as human activity begins to alter this ecologically intact land surface through development, there is increasing potential to affect ecosystem structure and function at a broad scale. In part, this is because individual projects must be linked by regional infrastructure, such as roads, airstrips, and transmission corridors. Transportation and transmission infrastructure has the potential to cause significant regional environmental impacts, including the creation of physical barriers to animal movement, habitat fragmentation, including stream habitats that are critical for spawning and movement, alteration of soil properties and surface water flows, and increased access through otherwise inhospitable terrain for invasive species, as well as predators, and hunters and anglers. These changes in turn alter interspecies dynamics and affect the abundance and distribution of species. Perhaps most important, however, the effects of roads are incremental and cascading. Once one road is built, to serve a single purpose or development project, it opens up the potential for further development, and creates pressure to build more road networks and power transmission lines. Well-planned and well-managed infrastructure is therefore a critical component of land use planning for the Far North.

Currently, the Far North has only two permanent inter-community gravel roads and one railroad to Moosonee; otherwise the region is served by airports and a network of winter roads. A major power corridor has been constructed from Otter Rapids on the Moose River through the James Bay communities to the Victor Mine, but no permanent road (if indeed one is necessary) has yet been built to service it. Several major corridor projects have, however, reached the feasibility or engineering stage at this time, including a high-voltage transmission line, a new 350-kilometre railroad link to the Ring of Fire chromite-nickel-copper-gold deposits near McFauld's Lake, and a year-round road to connect four First Nation communities and the Town of Moosonee on the west shore of James Bay to Highway 11.

First Nations communities are also discussing the possibility of an all-season road from Red Lake to Pikangikum and Sandy Lake, through the Whitefeather Forest areas. Even if new roads are unpaved and experience little traffic volume compared to southern Ontario, significant impacts on sensitive northern environments should be expected, particularly if the build-out of road networks is not carefully planned at a regional scale and cumulative effects are not carefully (re)assessed with each individual project.

The Path Forward

The future holds great uncertainty, not just in the location and nature of development, but in the influence of a changing climate on natural systems. The change that is projected could bring important socio-economic opportunities to Far North communities, but also change to the region's ecosystems.

In the short time the Science Advisory Panel has been convening, development interest in the Far North has dramatically heightened and at least 50 commitments and agreements are reported to be already moving ahead in the absence of formal land use planning. At the same time, global climate change, mobility and technology are accelerating the predicted trajectories of environmental and social change in the region. The Panel is deeply concerned about the potential for inadequately planned and monitored development to compromise ecological integrity in the region, and thus the ability of communities and governments to achieve all the objectives of the draft Far North legislation, including sustainable development for the benefit of First Nations.

Partners in planning for land use have a responsibility to advance Far North development in a manner responsive to community based planning, while meeting regional and international expectations and commitments. This requires careful attention to the maintenance of biological diversity and ecological functions, including carbon storage and sequestration, through the conservation of natural ecosystems. The Panel urges adherence to principles even, or perhaps especially, for interim development before community based plans are in place. To do otherwise is to risk inadvertent and irreversible environmental damage and erosion of the region's ecological resilience, even before the full effects of climate change and widespread human activity are known.

Planning across the entire region will of course be challenging. It will not be enough to consider resource sectors or protected areas singly and in isolation. Rather, it will be necessary to focus on the maintenance of ecological flows at multiple scales – the movements of organisms, water, and nutrients, and their interactions with different disturbances, both human and natural – across landscapes and planning units. This in turn requires comprehensive and coordinated planning and management of all landscape components and uses – planning, in other words, for conservation landscapes. This principle applies urgently and particularly to this region, at this time, because of the Far North's unique character, the changes that are predicted for it, and the needs of its communities. There is emerging but clear scientific evidence that the ecosystems of the Far North will be subjected to a magnitude and rate of climate change that exceeds historic levels. They may well be pushed beyond their natural, dynamic states, making them more vulnerable to negative impacts associated with development activities.

Conventional approaches to land use planning will not be sufficient to meet the purpose and objectives set out in the proposed Far North Act. They have been designed for landscapes that are already greatly altered from their original condition, where the goal is to protect the "best of what is left" for conservation purposes. In the Far North, it is necessary to reverse this approach, and consider how much development can be supported such that the natural and cultural values and integrity of the region are not compromised by development activities. This report recommends a regional-scale "conservation-matrix" model for land use planning, encompassing large core protected areas that serve as landscape-level benchmarks; site-specific protected areas, geared to protecting specific features; active management areas, where development and settlement are actively occurring; and the surrounding landscape, or "conservation matrix", within which the other three elements are embedded, and which they support.

Careful planning can help to minimize unanticipated impacts, and protect the region's ecological resilience as the climate warms and the human footprint expands. But surprises are inevitable, and we must be prepared for economic development to result in unintended ecological consequences. Those risks can be minimized by adopting key planning principles, based on both scientific and traditional knowledge, to improve our understanding of the probable outcomes of different land use scenarios with respect to achieving planning objectives. For example, the Far North represents an ecologically intact situation where ecological connectivity can be assumed at the outset. A fundamental goal of conservation planning will therefore be to ensure the region does not lose this attribute as land use changes become more prevalent. Yet because our knowledge of these systems is still rudimentary, the systems themselves are dynamic, and the impacts of climate change are as yet uncertain, it is difficult to predict the outcomes of management strategies. This uncertainty also increases the risk of failure to achieve planning objectives at both community and regional scales. For that reason, this report emphasizes the need for adaptive management, a structured process of learning that recognizes that unknowns and uncertainty exist in the course of achieving any natural resource management goals. Adaptive management allows adjustment of management strategies as information about the system improves. It means designing and implementing resource development activities in an incremental fashion, carefully documenting effects at each stage, and making course adjustments when and where necessary in accordance with new information. The benefits of adaptive management are many and include significant reductions in risk, dramatic increases in the transparency of decision-making, and a solid knowledge platform on which to base the choice of sustainable activities. The implementation and monitoring of management options can also create economic and employment opportunities.

New development in the Far North, one of the world's most ecologically intact landscapes, must be planned and managed such that communities can achieve their planning objectives, including social and economic development, while protecting the integrity of broad-scale systems and processes even in a changing climate. The Panel believes that a conservation-matrix model for Far North land use planning, supported by adaptive management, should enable sustainable development that benefits the region and its communities. Such an approach will require sustained commitment to the collection and sharing of information, both aboriginal and scientific, about the Far North.

Recommendations (Refer to Chapter 5 for the full text of these recommendations)

1. **Create a coordinated government-wide strategy for the management of interim and ongoing development**
2. **Immediately designate the 'Ring of Fire' as a priority management area with an interim sub-regional planning process**
3. **Immediately establish the Far North Land Use Strategy**
    - 3.1 Conduct land use planning to protect ecological integrity of the region as a whole, while also achieving socio-economic objectives
    - 3.2 Mitigate climate change by preventing or minimizing the loss of carbon storage in biomass and soil
    - 3.3 Consider the impacts of climate change in land use planning
    - 3.4 Establish a framework for protecting areas of cultural and ecological significance
    - 3.5 Use watersheds or other natural boundaries as the basis for establishing protected areas
    - 3.6 Coordinate planning and management across administrative boundaries

4. Plan development incrementally, in a considered, proactive fashion

- 4.1 Assess and manage cumulative impacts
- 4.2 Maintain the existing moratorium on large-scale hydro-electric development and extend it to include inter-basin water diversions
- 4.3 Plan transportation and transmission corridors in a coordinated fashion, recognizing community needs and protecting significant ecological features
- 4.4 Prevent the introduction of invasive species

5. Apply the best continuous learning approaches through adaptive management

- 5.1 Base management decisions on the best available knowledge, but regularly revisit and revise strategies as the knowledge base improves
- 5.2 Support planning and management with an appropriate decision-support system

6. Provide communities and governments with the necessary information resources for planning and management

- 6.1 Create a Far North information system to facilitate the use of best available knowledge, including aboriginal traditional knowledge
- 6.2 Improve the available information base through a comprehensive inventory, enhanced monitoring and special studies

1.0

INTRODUCTION

1.0 INTRODUCTION

1.1 THE FAR NORTH SCIENCE ADVISORY PANEL

In December 2008, the Ministry of Natural Resources established the *Far North Science Advisory Panel* of experts in a variety of fields to provide scientific and technical advice on how to achieve the government's vision for the Far North. From December 2008 to December 2009, we held 10 meetings over 15 days and hosted a two-day workshop. The workshop was also attended by members of the *Far North Advisory Council*, who had recently submitted their own report. During this gathering, the two panels had an opportunity to meet jointly and consider matters of mutual interest. Members of the Science Advisory Panel also attended the three-day Science for a Changing North Workshop held at Laurentian University in late October 2009. Finally, we have benefited from dozens of presentations by a variety of experts from inside and outside government.

The members of the Far North Science Advisory Panel are:

David Pearson (Chair) – *Professor, Department of Earth Sciences, Laurentian University*
Ken Abraham – *Research Scientist, Ontario Ministry of Natural Resources*
John Gunn – *Canada Research Chair in Stressed Aquatic Systems, Laurentian University*
David Lean – *Professor, Department of Biology, University of Ottawa*
Tim Lynham – *Forest Fire Research Scientist, Canadian Forest Service*
Justina Ray – *Executive Director, Wildlife Conservation Society Canada*
John Riley – *Chief Science Officer and National Director, Conservation Strategies, Nature Conservancy of Canada*
Nigel Roulet – *James McGill Research Professor of Geography, McGill University*
Fiona Schmiegelow – *Director, Northern Environmental and Conservation Sciences Program, University of Alberta*
Sean Thomas – *Canada Research Chair in Forests and Environmental Change, University of Toronto*
Stephen Woodley – *Chief Ecosystem Scientist, Parks Canada*

The Panel was very fortunate to have the participation of **Cathy Nielsen**, Senior Science Advisor, Far North

Branch, Planning and Information, as the liaison for the Ministry of Natural Resources and coordination for technical support. **Dr. Isobel Heathcote** was invaluable as technical editor for this report. Her exceptional skill in synthesizing our discussions and her painstaking care in making sense of a blizzard of additions and changes to the chapter drafts prepared by teams of Panel members added immeasurably to the results of our work.

The panel would also like to acknowledge the contributions of **Jane Toppozini**, **Lauren Toppozini**, **Melanie Bell** and **Karen Saunders** from the Far North Branch, (OMNR) for report design and layout, map production and research on supporting statistics, as well as the many other staff who provided information and presentations.

Terms of Reference

The Terms of Reference that have guided our work relate directly to achieving the broad vision for the Far North expressed by the Premier in June 2008 when the Far North Planning Process was announced. We understand that the Panel's advice will be used in the application of science to the identification, discussion and evaluation of policy options in the development of a Land Use Planning Framework for the Far North. We have drawn our understanding of the policy framework from the draft of Bill 191, *The Far North Act*, (as amended in Committee October 22, 2009) as it stands at the time of writing our report. We have also referred to the draft Proposed Growth Plan for Northern Ontario released on October 26, 2009, especially the recommendations and actions, and we have considered the consensus advice provided to the Minister of Natural Resources by the Far North Advisory Council in March, 2009.

We understand from the draft legislation that a Far North Land Use Strategy will be developed and that it will include policy statements on matters that require consideration of science. We also recognize the importance of community based land use planning, and the challenges of integrating community based planning with broader-scale conservation considerations.

We have attempted to put our recommendations into this dynamic context and to frame them in a way that engages with the policy development process, as well as with the government's intent for a balance between conservation and development as expressed in draft Bill 191, *The Far North Act*.

The Purpose and Functions of the Panel are described in its Terms of Reference (Appendix A), and include the provision of the best scientific and technical advice to the Minister of Natural Resources on how to achieve the Government's vision for the Far North. This role extends to advice on current and emerging threats to the ecosystems of the Far North, and the availability of scientific knowledge to address those issues.

1.2 BILL 191: THE FAR NORTH ACT (AS AMENDED OCTOBER 22, 2009)

The science-related parts of the Government's vision are reflected in the following extracted sections and subsections of Bill 191 (as amended October 22nd, 2009). We believe our recommendations are structured and focused in a way that will relate well to the discussion of options in the context of the objectives, strategies, and policy statements in those sections.

Objectives for land use planning

6. The following are objectives for land use planning in the Far North:

    1. A significant role for First Nations in the planning.
    2. The protection of areas of cultural value in the Far North and the protection of ecological systems in the Far North by including at least 225,000 square kilometres of the Far North in an interconnected network of protected areas designated in community based land use plans.
    3. The maintenance of biological diversity, ecological processes and ecological functions, including the storage and sequestration of carbon in the Far North.
    4. Enabling sustainable development that benefits the First Nations.

Far North land use strategy (excerpt from Section 7)

7. (4) (b) policy, scientific and technical guidelines that the Minister establishes for the purpose of land use planning in the Far North;

   (b.1) policies relating to, ...

      (ii) categories of land use designations in a planning area and the land uses and activities that are permitted in a category of land use designation, and

      (iii) categories of protected areas and the land uses and activities that are permitted in a category of protected area; ...

Far North policy statements

7. (6) The Minister shall prepare policy statements which may relate to the following matters in the Far North ...

    1. Cultural and heritage values.
    2. Ecological systems, processes and functions, including the storage and sequestration of carbon.
    3. The interconnectedness of protected areas.
    4. Biological diversity.
    5. Areas of natural resource development for potential economic development.
    6. Electricity transmission, roads and other infrastructure.
    7. Tourism.
    8. Other matters that in the opinion of the Minister are matters of provincial interest to land use planning.

2.0

ECOLOGICAL OVERVIEW

2.0 ECOLOGICAL OVERVIEW

The Far North of Ontario straddles two continental landscapes, the Boreal Shield[2]* (46% of the region's land area), and the Hudson Bay Lowland (54%). The differences between these – one lies on Precambrian bedrock and glacial sediment, and the other on limestones and marine clay – manifest themselves in distinct environmental, economic and cultural realities. The Far North also faces the Arctic Ocean, which confers on it yet another set of influences and potentials (Fig. 1).

This section outlines the range of significant features and phenomena that are interconnected within and beyond the Far North by ecological processes that function at multiple scales. The region's natural ecosystems remain relatively undiminished by habitat loss and fragmentation. As a result, the region has provided stable and beneficial ecological services over millennia. As climate change proceeds and the human footprint widens and deepens, it is certain that the complex interrelationships of these ecosystems will change. The extent of those changes will depend on the land use decisions that are made, and the degree to which community based plans are coordinated with a regional-scale conservation strategy.

Recognition of the interdependency of water, climate, geology, wildlife and communities is key to informed decision making. Water links the Far North's ecosystems and communities to each other and to the surrounding environment. All of the region's people and organisms make direct use of surface waters, both treated and untreated; the overall water balance is particularly important for providing water and food, maintaining stored carbon in wetlands, and retaining other elements, including toxic heavy metals, in safe systems.

Almost a tenth of the surface area of the Far North is covered with lakes and rivers. Three of Canada's largest rivers, the Albany, Moose and Severn, cross the region, and three other major rivers lie entirely within it, the Winisk, Attawapiskat and Ekwan. Together, these systems carry the equivalent of more than half the annual flow of the Great Lakes into the St. Lawrence River[1].

Their fresh water maintains low salinity in James Bay, and helps to make its coastal marshes immensely biologically productive. Hudson Bay and James Bay similarly exert an influence on the Far North's weather patterns and climate, moderating temperature and raising local atmospheric moisture levels.

---

*2 *The terms "Boreal Shield", "Canadian Shield", and "Ontario Shield" are often used interchangeably for the portions of the Shield that occur within Ontario. For the purposes of this report, we will use the term "Boreal Shield" or simply "Shield" to refer to the part of the Shield that lies within the Far North, and "Canadian Shield" more generally.*

The Hudson Bay Lowland is the globe's third largest wetland, and the largest in North America. Along the Hudson and James Bay coasts and farther inland, the Far North's wetlands and peatlands contain as much water as Lake Erie. The slow movement of this water into lakes and rivers is fundamental to the stability of these moist ecosystems and ensures that they remain "sinks" – storehouses – of the carbon, mercury and other materials stored in them. Changes in these water flows, whether caused by a warming climate or through human activities on the land, will upset this equilibrium, and can tip these slow-moving systems into a new condition where they begin to release stored materials into downstream waters and the atmosphere. One of the most important elements of these connected water systems is the region's peatlands, which formed over the flat, impermeable clays laid down by a sea that covered the Hudson Bay Lowland 6,000 years ago. Saturated peats from 1 to 3m deep dominate the Hudson Bay Lowland, and support habitats such as bog, fen, marsh and swamp. Closer to Hudson Bay lie widespread tundra and permafrost peatlands. The seacoast is rising and at over a metre per century has the fastest rate of postglacial uplift (isostatic rebound) in North America. As it rises, the slope of the land flattens, and accumulates even deeper peats. Together, the peatlands in the Far North store more carbon than all the other natural ecosystems of Ontario combined. There is growing documentation of the role that peatlands play in cooling the global climate, and about a tenth of the cooling benefit of global peatlands comes from the Far North of Ontario. Climate change and human activity may alter those systems dramatically, however, altering storage regimes and releasing stored carbon to the atmosphere.

Another important feature of the Far North is the presence of permafrost – permanently frozen rock, soils, and peat – in the northern two-thirds of the region (Fig. 4). Permafrost creates some of the characteristic topographic features of the region, including peat mounds (palsas), and associated specialized habitats. Permafrost is extensive and continuous in northern portions of the Hudson Bay Lowland, but grows progressively more patchy and sporadic south, and into, the Boreal Shield. Tree cover in the Far North also exhibits a distinct latitudinal gradient, from sparse woodlands near the tundra of Hudson Bay, through intermittent taiga and rocklands, to true boreal forest in the southern portion of the region. In the central portion of the Far North, along the eastern boundary of the Boreal Shield, is the so-called "Ring of Fire", an arc-shaped, mineral-rich zone that is now the focus of intense mineral exploration activity.

Along this gradient from low-lying wetlands in the east to forested upland areas in the west and south, lie numerous ecosystems, some of them with unique assemblages of plants and animals. Wildfires play a rejuvenating role in forest ecosystems, but the frequency of wildfires will increase as the climate warms. Already, greenhouse gases released by wildfires are about 5% of the amount released by industrial sources in Ontario. This calculation is based on the release of 198 Mt/yr of industrial carbon dioxide equivalent (CO2e)[2] and the average annual release of 9.9 Mt/yr of CO2e from fires in Ontario[3]. Clearly, while these systems are adapted to the geology, the climate, and the flows of this intact northern region, a warming climate has the potential to alter existing patterns and flows across the region. Locally, human activity may have even more dramatic consequences for the protection of ecological integrity.

Table 1 provides a summary of the main demographic, biophysical, and economic characteristics of the Far North. Figure 5 provides locations for meteorology and stream flow stations in the Far North.

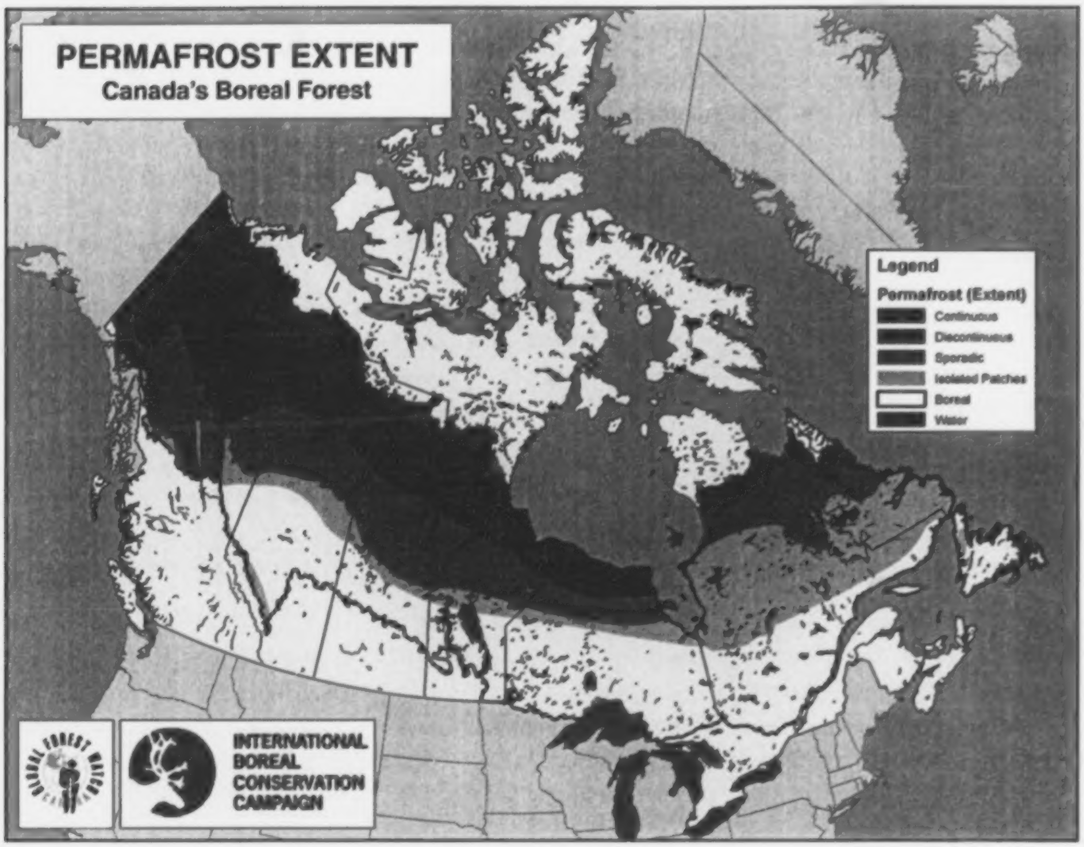


Figure 4. *Distribution of permafrost in Canada. Source:* http://atlas.nrcan.gc.ca/site/english/maps/archives/5thedition/environment/land/mcr4177

Table 1. Far North Facts and Figures

	Far North (Total)	Canadian Shield	Hudson Bay Lowland
Population	24,000	20,000	4,750
Youth population (under 16)	50%		
Number of communities	34	27	7
Physical and Biological			
Total area	451,808 km ²	206,253 km²	245, 555 km²
Open water (%)	10%	13%	7%
Marsh (freshwater and tidal)	0.3%	0%	0.5%
Bog and fen	47%	20%	69%
Tundra, palsa, and peat plateau (%)	0.6%	0.0%	1%
Forest, woodland and swamp (%)	35%	53%	20%
Rock barren (%)	0.2%	0.5%	0%
Burns and early regeneration (%)	7%	12%	2%
Ocean coast	1287 km**	-	1287 km**
Number of Species at Risk ***	11		
Number of Far North species tracked by the Natural Heritage Information Centre	161		

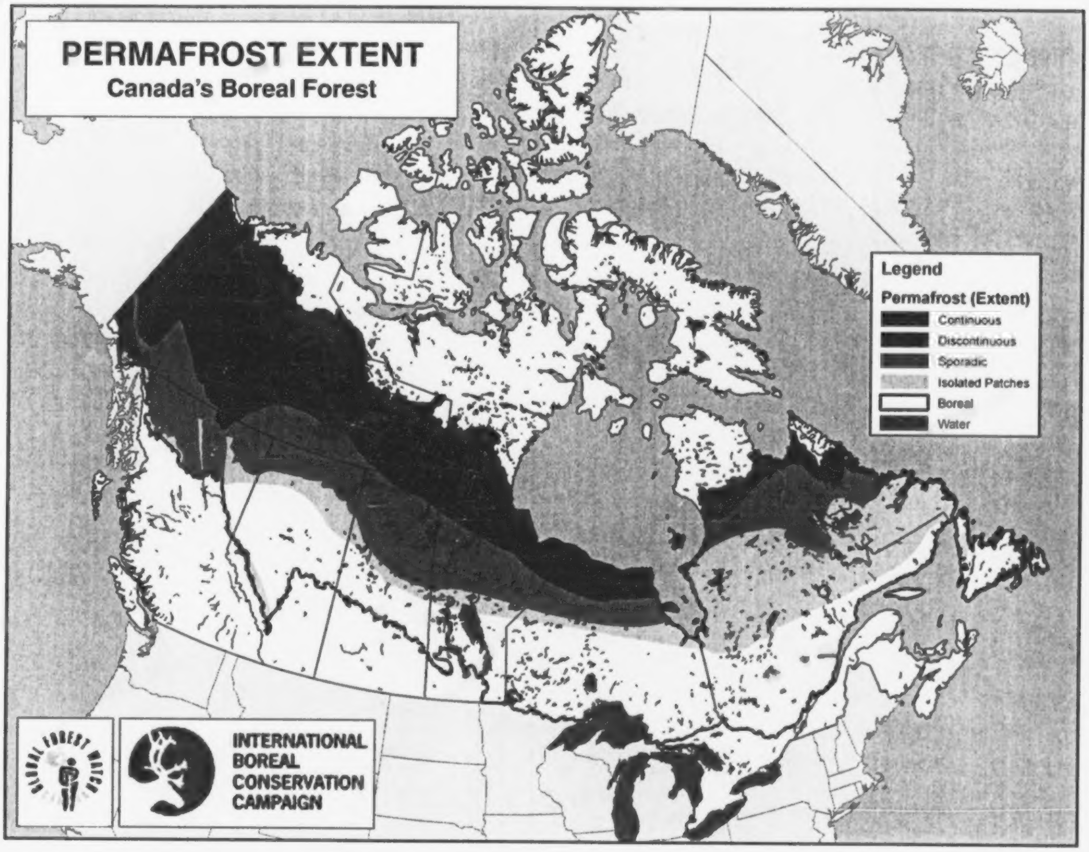


Figure 4. *Distribution of permafrost in Canada. Source: http://atlas.nrcan.gc.ca/site/english/maps/archives/5thedition/environment/land/mcr4177*

Table 1. Far North Facts and Figures

	Far North (Total)	Canadian Shield	Hudson Bay Lowland
Population	24,000	20,000	4,750
Youth population (under 16)	50%		
Number of communities	34	27	7
Physical and Biological			
Total area	451,808 km ^{2}	206,253 km^2	245, 555 km^2
Open water (%)	10%	13%	7%
Marsh (freshwater and tidal)	0.3%	0%	0.5%
Bog and fen	47%	20%	69%
Tundra, palsa, and peat plateau (%)	0.6%	0.0%	1%
Forest, woodland and swamp (%)	35%	53%	20%
Rock barren (%)	0.2%	0.5%	0%
Burns and early regeneration (%)	7%	12%	2%
Ocean coast	1287 km**	-	1287 km**
Number of Species at Risk ***	11		
Number of Far North species tracked by the Natural Heritage Information Centre	161		

Economy	Far North (Total)	Canadian Shield	Hudson Bay Lowland
Number comunities on hydro grid	10	4	6
Length-transmission corridors (km)	1,043 km	448 km	596 km
Number communities connected by:			
All-weather roads	4	4	0
Winter roads	34	27	7
Rail	1	-	1
Regional airport	1	0	1
Remote airports	28	23	5
Number of communities with broadband access	34	29	5
Number of active mines	2	1 (gold)	1 (diamonds)
Number unpatented mining claim units (400x400m) as of March 10, 2010	90,579	-	-
Number of unpatented mining claim units as of March 12, 2007	35,386	-	-
Area of land staked as of March 12, 2010	14,493 km^3	-	-
Area of land staked as of March 10, 2007	5,662 km^2	-	-
Potential commercial forestry	6-7%	11-12%	Local
Number of hunting/fishing base camps (satellite camps)	138	132	6
Potential hydropower sites (# identified for development)	199	62	37

	Far North (Total)	Canadian Shield	Hudson Bay Lowland
Ecological Processes at Scale			
Total stored Peatland Carbon (billion tonnes)	35.3	9.3	26
Estimated stored forest carbon (billion tonnes)	2.6	-	-
Estimated Annual stored carbon (million tonnes)	3.36	-	-
Wildfires (average annual burned area from 1980-2007)	150,000 ha	125,000 ha	25,000
Miscellaneous			
Number of meteorological stations****	5	2	3
Number of stream flow gauges	22	11	11 (7 on moose)
Number of peatland hydrographic stations	0	0	0
Existing protected areas	8.59%	-	-

*Estimated areas of vegetation types are tentative; revised provincial land-cover mapping is underway (2009).

**Based on the provincial boundary.

***Species on the Species at Risk in Ontario (SARO) List are: eskimo curlew, golden eagle, bald eagle, black tern, short-eared owl, yellow rail, wolverine, woodland caribou (boreal form), polar bear, lake sturgeon, and shortjaw cisco,

**** Environment Canada website

	Far North (Total)	Canadian Shield	Hudson Bay Lowland
Economy			
Number comunities on hydro grid	10	4	6
Length-transmission corridors (km)	1,043 km	448 km	596 km
Number communities connected by:			
All-weather roads	4	4	0
Winter roads	34	27	7
Rail	1	-	1
Regional airport	1	0	1
Remote airports	28	23	5
Number of communities with broadband access	34	29	5
Number of active mines	2	1 (gold)	1 (diamonds)
Number unpatented mining claim units (400x400m) as of March 10, 2010	90,579	-	-
Number of unpatented mining claim units as of March 12, 2007	35,386	-	-
Area of land staked as of March 12, 2010	14,493 km^2	-	-
Area of land staked as of March 10, 2007	5,662 km^2	-	-
Potential commercial forestry	6-7%	11-12%	Local
Number of hunting/fishing base camps (satellite camps)	138	132	6
Potential hydropower sites (# identified for development)	199	62	37

	Far North (Total)	Canadian Shield	Hudson Bay Lowland
Ecological Processes at Scale			
Total stored Peatland Carbon (billion tonnes)	35.3	9.3	26
Estimated stored forest carbon (billion tonnes)	2.6	-	-
Estimated Annual stored carbon (million tonnes)	3.36	-	-
Wildfires (average annual burned area from 1980-2007)	150,000 ha	125,000 ha	25,000
Miscellaneous			
Number of meteorological stations****	5	2	3
Number of stream flow gauges	22	11	11 (7 on moose)
Number of peatland hydrographic stations	0	0	0
Existing protected areas	8.59%	-	-

---

*Estimated areas of vegetation types are tentative; revised provincial land-cover mapping is underway (2009).

**Based on the provincial boundary.

***Species on the Species at Risk in Ontario (SARO) List are: eskimo curlew, golden eagle, bald eagle, black tern, short-eared owl, yellow rail, wolverine, woodland caribou (boreal form), polar bear, lake sturgeon, and shortjaw cisco,

**** Environment Canada website

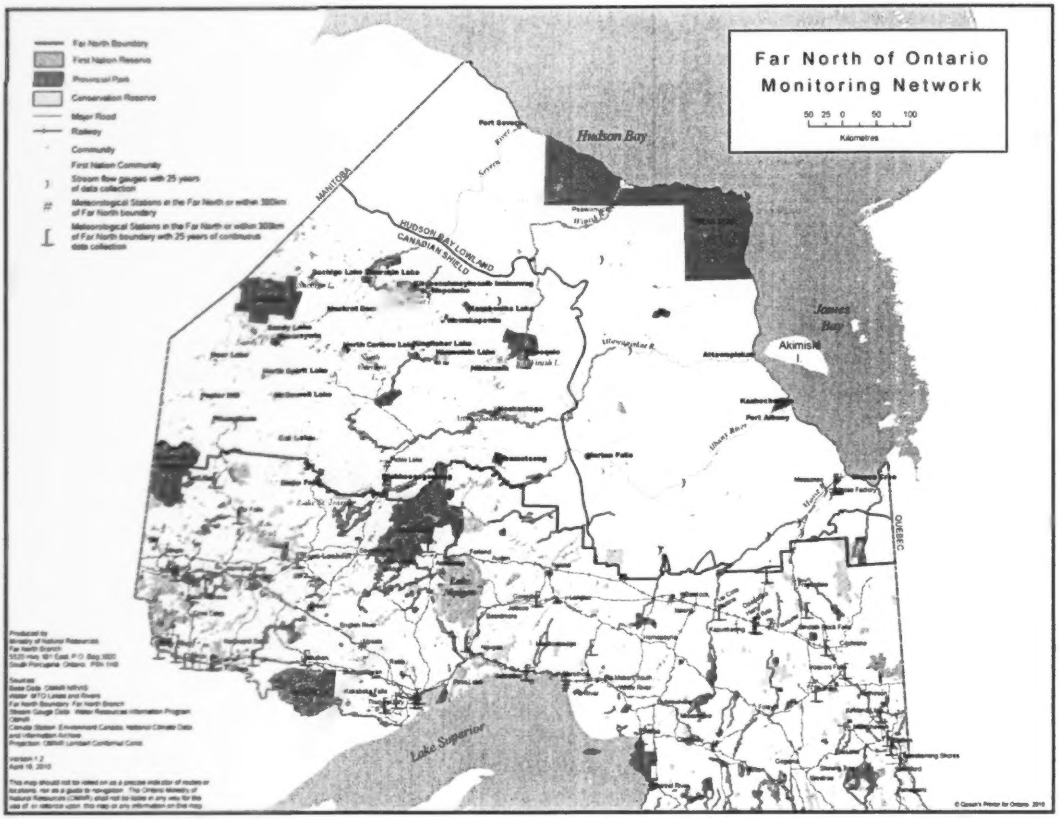


Figure 5. *Current monitoring networks in the Far North.* ***A.*** *Meteorological stations in Far North or within 300km of the Far North boundary, annotated to indicate which have more than 25 years of continuous data.* ***B.*** *Stream flow gauges with more than 25 years continuous data collection. Source:* ***A.*** *Meteorological source Environment Canada National Climate Change Data and Information Archive.* ***B.*** *OMNR, 2010* .

There is growing evidence that even in the absence of extensive human activity, the Far North's ecosystems are shifting as the climate warms. In the past fifty years, average precipitation increased and average air temperature in the Far North rose by 0.3 to 0.4°C. Polar bear are losing weight, and sea-run brook trout have died in warmed waters[4]. By 2050, however, it is projected that average temperatures and precipitation in the Far North will have increased enough to alter plant communities, degrade permafrost, lower water levels in lakes, rivers and wetlands, reduce ice cover on land and sea, and affect fish, wildlife and forests. While specific outcomes cannot be predicted with certainty, it is generally agreed that there has been no previous experience of such rapid rates of change. (Climate change is discussed in more detail in section 3.1.)

Other natural forces may offset some of these impacts. For example, while sea levels have risen about 0.2m in the past century (a rate that may triple in the next century), the predicted sea-level rise is less than the present rate of postglacial uplift of the coast, so sea-level changes may be less in the Far North than elsewhere. At the same time, however, Hudson Bay and James Bay are among the globe's southern most

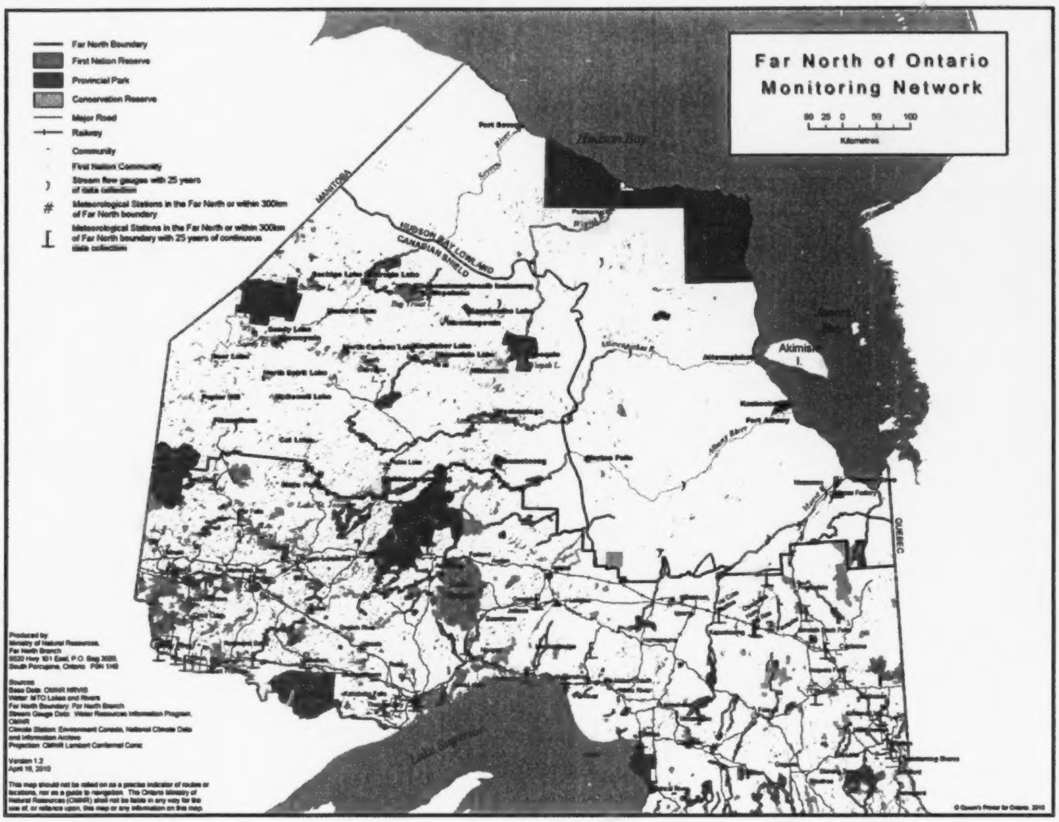


Figure 5. *Current monitoring networks in the Far North.* ***A.*** *Meteorological stations in Far North or within 300km of the Far North boundary, annotated to indicate which have more than 25 years of continuous data.* ***B.*** *Stream flow gauges with more than 25 years continuous data collection. Source:* ***A.*** *Meteorological source Environment Canada National Climate Change Data and Information Archive.* ***B.*** *OMNR, 2010* .

There is growing evidence that even in the absence of extensive human activity, the Far North's ecosystems are shifting as the climate warms. In the past fifty years, average precipitation increased and average air temperature in the Far North rose by 0.3 to 0.4°C. Polar bear are losing weight, and sea-run brook trout have died in warmed waters[4]. By 2050, however, it is projected that average temperatures and precipitation in the Far North will have increased enough to alter plant communities, degrade permafrost, lower water levels in lakes, rivers and wetlands, reduce ice cover on land and sea, and affect fish, wildlife and forests. While specific outcomes cannot be predicted with certainty, it is generally agreed that there has been no previous experience of such rapid rates of change. (Climate change is discussed in more detail in section 3.1.)

Other natural forces may offset some of these impacts. For example, while sea levels have risen about 0.2m in the past century (a rate that may triple in the next century), the predicted sea-level rise is less than the present rate of postglacial uplift of the coast, so sea-level changes may be less in the Far North than elsewhere. At the same time, however, Hudson Bay and James Bay are among the globe's southern most ocean bodies to freeze over each winter. Reduced ice cover in them may contribute to increased solar warming, also with unknown effects.

These brief examples provide several important lessons. The first is that the Far North's ecosystems are interconnected through the flow of water, air, materials, and organisms. Community based and broad-scale planning must consider these connections, which extend far beyond the local level and into neighbouring regions. Plans that do not reflect this connectivity are unlikely to be able to achieve their goals, because of the risk of unexpected outcomes and cumulative impacts.

A second lesson is that the Far North's ecosystems are naturally variable. Indeed, it is their adaptation to natural variation, through processes that operate at multiple scales, that allows them to rebound after major fires, weather events, and insect outbreaks. But we cannot push these systems too far, either through human action or with a changing climate. When these systems begin to experience change that exceeds natural variability, there is a strong likelihood that they will become unstable, with new physical conditions, new assemblages of plants and animals, and outcomes that are almost impossible to predict. We cannot control the impact of a changing climate on this region, but careful, adaptive land use planning can help to minimize the risks of too much anthropogenic change, implemented too quickly.

A third lesson is that community based and broad-scale land use planning now provides a collective opportunity to reflect on our shared knowledge of the region, and what is known and not known. The changes that are coming will have both predictable and unpredictable effects on the Far North's ecosystems. We need to bring all available knowledge – both aboriginal traditional knowledge and scientific knowledge – to bear on understanding these systems and informing land use decisions now and in the future.

The following sections describe the ecological components and processes of the Far North in more detail, and place them in the context of current human activity patterns.

2.1 HUMAN HISTORY

The Far North has been inhabited for thousands of years. Oral tradition and archaeological evidence demonstrate that aboriginal peoples have harvested caribou, fish, and fowl in the Far North for at least 5,000 years[5]. The first Europeans in the 1600s saw little of this value from their ships. Henry Hudson and his crew wintered on James Bay in 1610.[6] In 1631, Thomas James sailed to Hudson Bay and described "a most shallow and perilous coast." On shore, James "found the land utterly barren of all goodness."[7] Yet by 1670, the new Hudson's Bay Company had established a fur trading post and permanent settlement at the foot of James Bay[8]. It was that Company's direction to its men to study the natural history of the region that constituted its first scientific data[9].

A wealth of wild protein was needed to meet both aboriginal needs and the demands of Company posts. Armed with new tools, the Cree met the challenge, and grew the fur trade. Caribou, fish and fowl remained the staples. Company diaries list some fraction of this harvest. Between 1747 and 1781, a single post recorded a trade in 18,500 caribou. Severn House reported 2666 caribou skins in 1792-93, and York Factory 3417 skins in 1804-05. As the caribou declined, its hunt intensified until, in 1811-12, neither post reported any caribou skins[10].

Smallpox arrived in 1781, coming overland from the southwest and reaching Albany in 1783. Before, the Cree around the posts on Hudson and James Bay numbered perhaps 500 to 700, with another 1000 to 1400 in the interior. At a minimum, half of the population died as a result of exposure to smallpox. Other diseases took their toll as well[11].

The Hudson's Bay Company was the commercial venture that advanced the interests of Europe in most of central, western and northern Canada[12]. In 1869, one of Canada's first acts after confederation was to purchase the lands of the Hudson's Bay Company, for £300,000 cash and one-twentieth of its potential farm lands. In northern Ontario this ushered in an era of treaties, missions and educators. The boundary of Ontario was extended north to the Albany River in 1889, and then again to Hudson Bay in 1912. Trade shifted away from the coast to new southern access routes even though, by 1920, the communities at Albany, Marten Falls, Fort Hope and Attawapiskat were still supplied by water from James Bay while Fort Severn, Trout Lake and Weenusk were still supplied from York Factory, Manitoba[13]. The railway to Moosonee was finished in 1932, and the road to the Pickle Lake mining camps in 1956.

In 1969 the Far North had no television, no AM or FM radio, one airport (Moosonee), two other airfields, one of them military (Winisk). Only the Moosonee airport had scheduled air service more than three times a week; other air access was by float plane[14]. Today, airports, airstrips, winter roads, transmission corridors, and broadband communications are in place and expanding. Prospecting and planning for minerals, energy and transportation are more intensive than ever. Change has always been part of life in the Far North, but it will now occur more rapidly than ever before.

2.2 GEOLOGY AND CLIMATE

2.2.1 Geology

The Far North of Ontario is divided into two geological regions: the Boreal Shield (46% of the Far North), an area of irregular topography controlled and underlain by Precambrian igneous and metamorphic rocks (bedrock-dominated terrain); and the Hudson Bay Lowland (54%), an area underlain by relatively flat-lying sedimentary rocks of Paleozoic and Mesozoic age covered by loose glacial and marine sediment.

The sedimentary rocks of the Lowland are shaped like a wedge, thickening to the north and forming the southern rim of the broader Hudson Bay sedimentary basin (Fig. 6). They are similar in age (460–420 million years) to the Niagara Escarpment and to the limestone that also overlies the Shield rocks on many Arctic coasts and islands. The thickness of limestones over the Shield rock is more than a kilometre at the coast of Hudson Bay[15] and in the Moose River basin southwest of Moosonee[16].
The Precambrian Shield in the Far North was built by a succession of mountain-building episodes between about 2.72 and 2.68 billion years ago that produced mineral-bearing rocks and extensive linear fractures. It is similar to the better-studied Shield area to the south where mineralization of long standing industrial interest includes nickel, copper and gold. Those metals have already been found In the Far North as well commercially important deposits of chromite and diamonds; see section 3.2.4.

The latest of a succession of ice sheets that spread over Ontario several times in the last 2.7 million years melted away in the Far North about 8,000 years ago. Gravel, sand, silt and clay in a wide variety of landforms were left by the melting ice on the smoothed and scoured bedrock of the Shield[17]. Under-ice streams carried

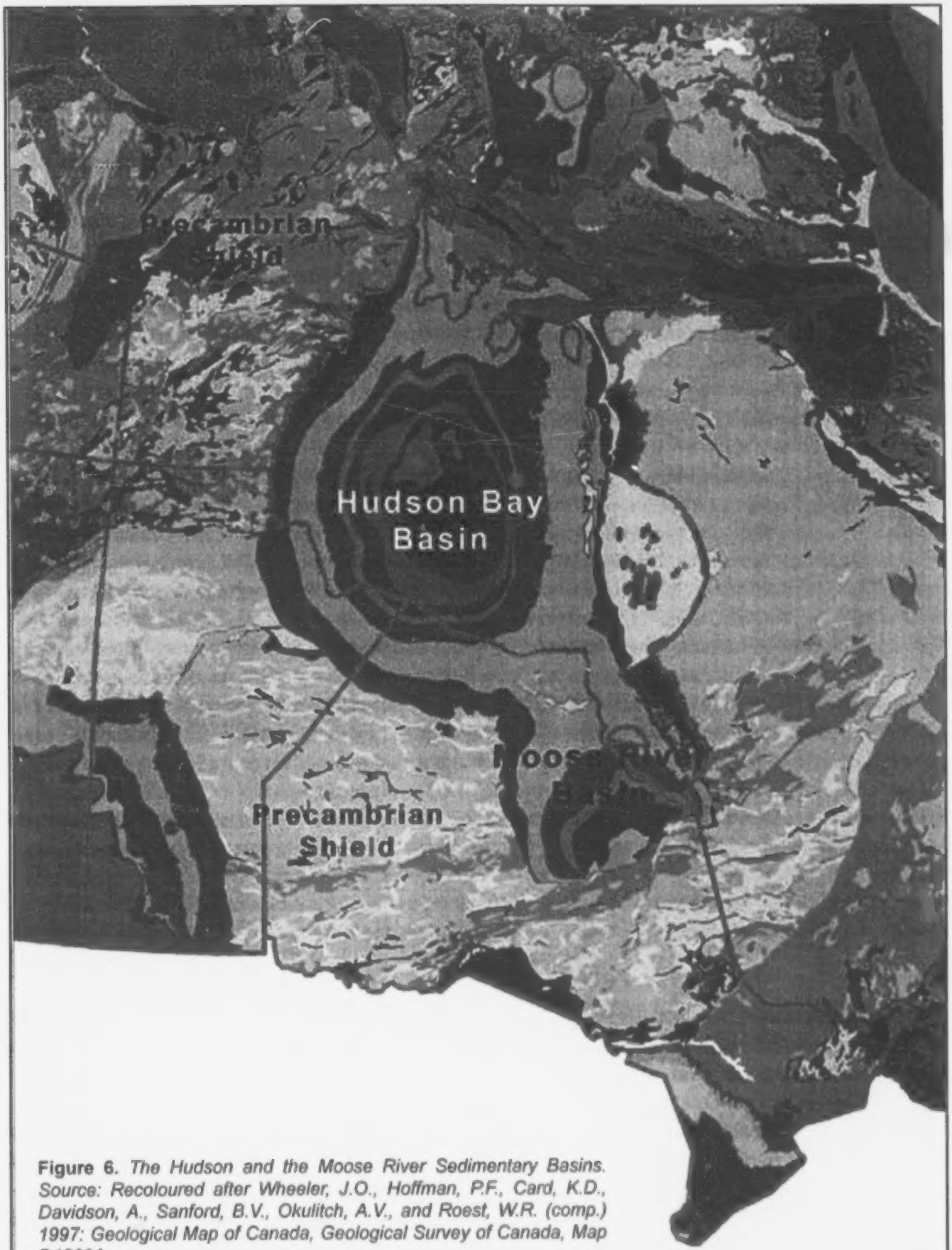


Figure 6. *The Hudson and the Moose River Sedimentary Basins. Source: Recoloured after Wheeler, J.O., Hoffman, P.F., Card, K.D., Davidson, A., Sanford, B.V., Okulitch, A.V., and Roest, W.R. (comp.) 1997: Geological Map of Canada, Geological Survey of Canada, Map D1860A.*

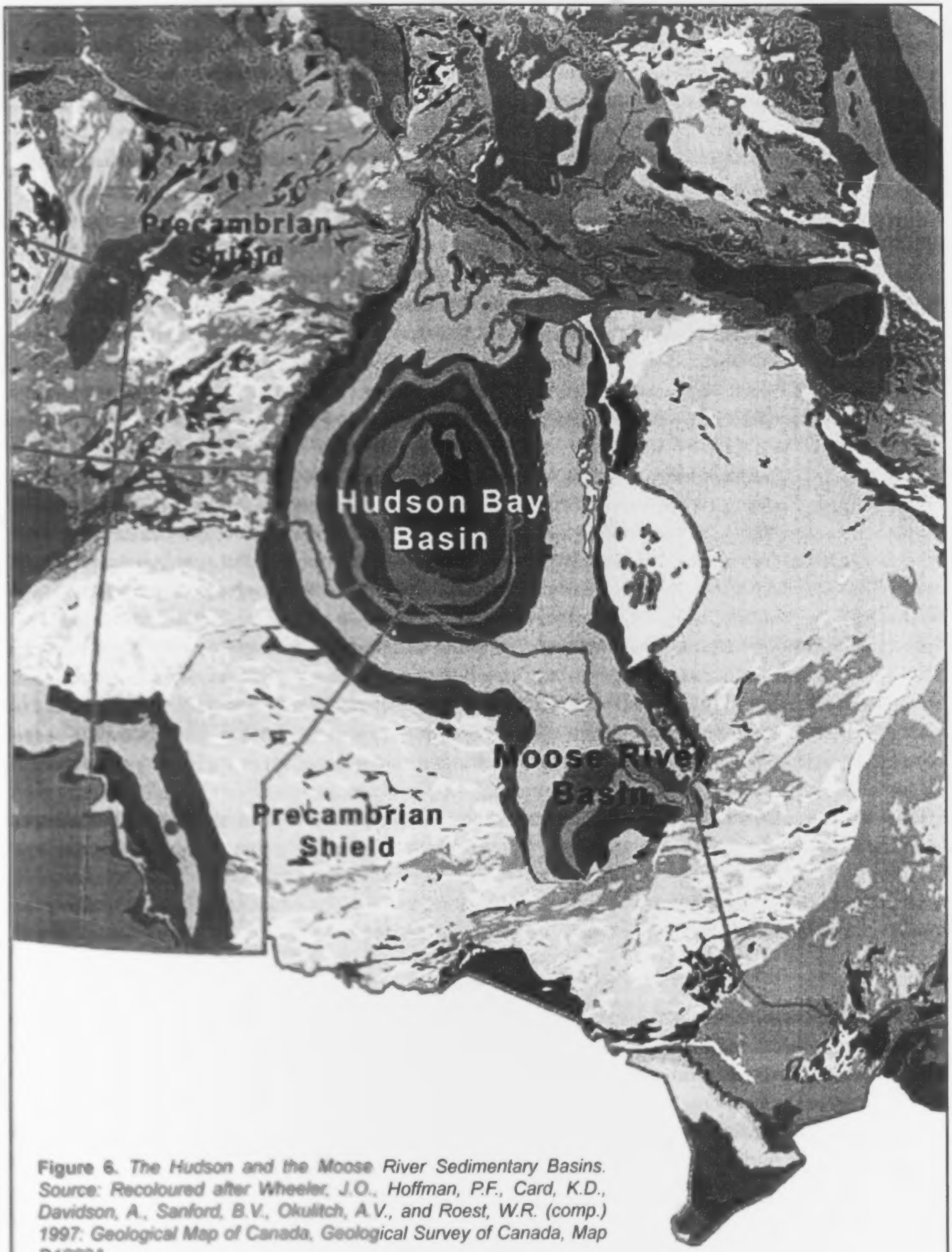


Figure 6. *The Hudson and the Moose River Sedimentary Basins. Source: Recoloured after Wheeler, J.O., Hoffman, P.F., Card, K.D., Davidson, A., Sanford, B.V., Okulitch, A.V., and Roest, W.R. (comp.) 1997: Geological Map of Canada, Geological Survey of Canada, Map D1860A.*

large volumes of sediment to lakes at the ice margin where it was deposited in deltas, sandy plains and on muddy lake floors. River bed sands or eskers, abandoned shoreline beaches and sandy spits, as well as unsorted, under-ice tills and large, mounded, ice margin end-moraines are very evident on the landscape. Lakes and wetlands lie in scoured bedrock basins and depressions on plains of flat lying sediment[18].

Seawater flooded the Hudson Bay Lowland when the ice sheet melted and waves washed and sorted much of the glacial sediment. The land has since rebounded about 285m, moving the shoreline to the north and raising a succession of up to 185 abandoned beaches[19]. As the land continues to rise at about 10 mm/yr and the shore retreats, rivers are cutting into the glacial till. Between the incised river channels, the land surface is very gently sloping and underlain by till or marine sand, silt and clay on which wetlands have since developed.

2.2.2 Climate and Permafrost

In the eastern part of the Far North, the Hudson Bay Lowland's subarctic climate plays a defining role in its water and carbon regimes, its ecosystems, its wildlife, and its community development. The climate there is strongly cooled and moistened by Hudson Bay and James Bay. These two waterbodies freeze over in winter, and, in late July, fifty percent of offshore waters in some areas between Fort Severn and Cape Henrietta Maria can remain covered in ice[20]. Large mammals of the region, for example polar bear, rely on this ice cover for hunting and access to prey. In contrast, the Shield is strongly influenced by the continental climate of the North American interior, and is warmer and drier than the Hudson Bay Lowland.

The summer position of North America's Arctic Front is forced south by the cold air over Hudson Bay[21], which generates persistent summer onshore winds and land-sea breezes that lower temperatures and increase fog. This is most evident within 15 to 20km of the coast, where evapotranspiration rates are at their lowest levels, 25-40% below those farther inland[22]. Similar maritime-arctic climates occur along the coasts of Labrador and the Aleutian Islands, also because of cold offshore waters. This cool, moist climate contributes to the stability of coastal wetlands and peatlands, and thus the maintenance of carbon stores. To the west, and in the Shield, the climate is drier, and this influences the dryness of upland habitats and leads to a higher frequency of natural fires.

Climate trends are illustrated in Table 2 for three Hudson Bay Lowland meteorological stations compared with the nearest interior station on the Canadian Shield to the south, and Toronto. There are 246 meteorological stations used to calculate Ontario climate norms and, of these, only three are located in the Far North. This is among the weakest meteorological networks in Canada.

As noted earlier, one of the most widespread effects of climate in the Far North is the occurrence of permafrost in the northern two-thirds of the region (Fig. 4). While permafrost occurs in bedrock, soils and peat, peat is a superior thermal insulator. This conserves permafrost so effectively that the southern limit of sea-level permafrost occurs, continentally, in the peats of the James Bay lowland. Permafrost-influenced features in the region include coastal beachridges, wetlands, tundra and ice-wedge polygons; stone circles, and frost boils in mineral soils and rocklands; interior palsas (raised mounds of expanded peat) and coalesced palsa fields (peat plateaus); thermokarst lake plains; ice-laminated river levees; and, southward, treed bog islands in peatland complexes.

Table 2. Climate Data[23]

	Winisk	Big Trout Lake	Moosonee	Cochrane	Toronto
Mean Daily Temperature (°C)	-5.5	-3.0	-1.1	-0.6	7.3
Annual Growing Degree Days Above 5°C	625	1025	830	1300	2300
Mean Annual Precipitation (mm)	608	581	728	885	762
Annual Days with Precipitation	164	161	173	149	137

Within 75km of Hudson Bay (and up to 100km in some places), permafrost dictates the character of the landscape. Permafrost underlies almost all landforms, and extends north under Hudson Bay. Permafrost ecosystems have a summer active layer, a depth of ice thaw that permits vegetation growth and water flow and retention. Peat plateaus within 100km of the Hudson Bay coast generally have active layers about 35cm deep in late summer, over about 3m of frozen peat[24].

Southward is a broad zone of discontinuous permafrost, where isolated permafrost features such as palsas, peat plateaus and treed bog islands occur, especially in lowlands. Further south again, in the Albany basin, and again particularly in the James Bay Lowland, permafrost features are even more sporadic, and permafrost is very infrequent on the Canadian Shield.

Raised permafrost sites are frequently dominated by lichens, the high light reflectance (albedo) of which helps maintain cold subsurface temperatures. Wildfires remove lichen cover, lower the albedo, and deepen the summer active layer. Climate warming may have similar but broader scale effects (as well as increasing wildfire frequency), including increased runoff and erosion or collapse of frozen terrain and levees, and the release of stored carbon as emissions. Along the Hudson Bay coast, permafrost deterioration is also exacerbated by overgrazing by geese, which also reduces surface albedo and increases thaw[25].

2.3 HYDROLOGY AND WATER QUALITY

2.3.1 Hydrology

Water and associated aquatic systems are connected ecological systems, linking terrestrial landscape elements, and thereby contributing to ecological integrity[26]. The structural patterns formed by any drainage network of rivers influence environmental features such as watershed geochemistry, topography, vegetation and climate[27]. Both headwaters and downstream areas perform a variety of ecological functions. Headwaters act as sources of water, sediments, dissolved organic carbon, and nutrients[28]. Ecological conditions in the headwaters influence the function, productivity and biodiversity of downstream areas[29], and act as important source areas for biodiversity[30]. Many human activities can alter hydrological connectivity, including those associated with hydro-electric development (dams and associated flow regulation), water extraction and diversion[31] and road building[32].

Water and wetlands dominate much of the Far North. Almost a tenth of the region is open, fresh, surface waters – lakes, rivers, streams and ponds – and an even higher percentage of the Boreal Shield is open water. Hydrologically, Ontario is more closely linked to the Arctic Ocean than to the Atlantic Ocean. Approximately 67% of the surface area of Ontario drains to Hudson Bay, either directly or through Manitoba (Fig. 7). The Hudson Bay watershed receives about 54% of the volume of Ontario precipitation, and 57% of Ontario's runoff drains into Hudson Bay and James Bay[33].

Lakes with surface areas greater than 10 ha cover about 28,000,000 ha or about 8% of the surface area of the Hudson Bay-James Bay watershed[34]. The size and number of these lakes has been enumerated in each subwatershed but, because only low-resolution maps (1:250,000) have existed for the Far North until now, the vast number of smaller ponds and lakes have not been counted. Natural Resources Canada, OMNR and partners are now developing 1:50,000 maps for the Far North, but waterbody analysis remains incomplete.

Although most of the Far North's water systems are unaltered by humans, some major interventions have occurred on the region's largest rivers. There are three diversions of water from the Albany River system, two of them redirecting 3.4% of the flow of Ontario's Arctic watershed for hydro-electric production and water-level maintenance in the Great Lakes basin. Another 2.0% of the Ontario Arctic watershed is diverted west to Manitoba's Nelson River, through the English River system, also to generate hydro-electric power and maintain water levels[35].

The Moose River watershed has also been developed directly for hydropower, starting in 1910 and with most of the present development completed by the mid-1960s. Fifteen stations generate more than two megawatts on the Mattagami River and Abitibi River tributaries, exporting south along major transmission

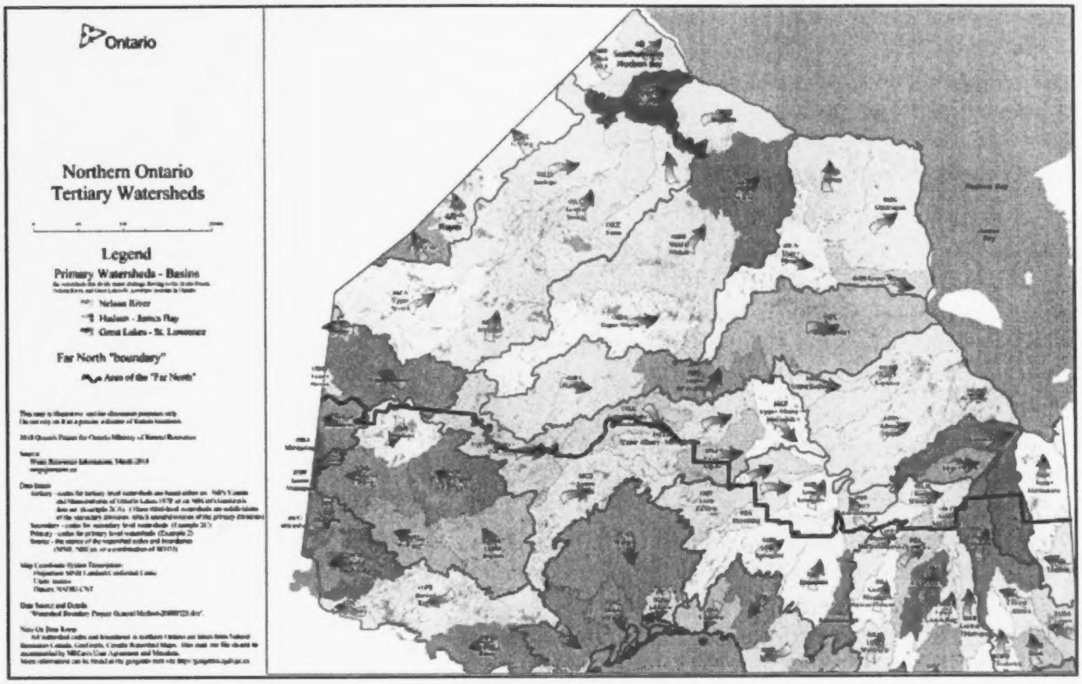


Figure 7. *Drainage Basins of the Far North. Source: Water Resources Information Ontario, 2010*

corridors. Expansion and full development of the Mattagami, Abitibi, and lower Moose rivers is under study. Presently, there are three hydro-electric generating stations (GSs) in the Far North. Two of the three are located on the Moose River (Ontario Power Generation's Kipling (83 MW) and Harmon (81 MW) GSs) and one on the Severn River (Hydro One Remote Communities' Deer Lake (0.5 MW) GS).

The Kipling and Harmon GSs, and upstream of the planning area, Little Long and Smoky Falls GSs, form OPG's Lower Mattagami complex of "peaking dams," with electricity production exported south along major transmission corridors. These dams have major downstream dewatering and flooding impacts. OPG is presently preparing to expand production capacity in the Lower Mattagami complex by about 450 MW, and additional greenfield development farther downstream along the Mattagami and Abitibi Rivers is under study[36] (see section 3.2.3).

The importance of the quality and quantity of water to the long-term ecological, economic and social sustainability of the Far North cannot be overstated. Healthy water systems connect the region's ecosystems, contribute to the safe storage of carbon, mercury, and other materials, and moderate climate. They supply drinking water for residents of the Far North and support the fish and wildlife that residents consume. Yet despite the importance of water to the ecosystems of the Far North, there are, at present, few data on the water resources of the region. The information summarized here relies primarily on sources that are more than 30 years out of date. There are only 7 hydrographic stations in Ontario's entire Hudson Bay basin, of which the Far North is a portion[37], and no peatland stations at all. Indeed, in 2009, Ontario's Hudson

Bay watershed was identified as having one of the most deficient systems in Canada for measuring basic streamflow. The OMNR has begun a major mapping and monitoring exercise for the region, but that work is still underway, and our understanding of the region's hydrology therefore remains incomplete.

2.3.2 Surface Water Quality

Very little water quality data exists for the Far North. Some sampling of chemical and physical parameters related to fish productivity (e.g., Secchi disk clarity, specific conductance, total dissolved solids) was included in OMNR fish surveys of Aquatic Habitat Inventory (AHI) lakes in the 1970s and 1980s, and OMOE conducted intensive surveys of 28 Far North lakes in the early 1970s[38]. Even fewer rivers have been studied. However, even without current survey information, it is probably safe to say that the water quality of most of the lakes, rivers and streams in the region is unlikely to show significant effects of local human influence, because population density in the area is so low and industrial development so sparse. This has, however, made little difference to the tragic condition of drinking water in some First Nations communities, which has been impaired by poor water-system design and inadequate sanitation conditions[39].

Available data suggest that most of the region's surface waters, especially on the Lowlands if less so on the Shield, have sufficient buffering capacity against the effects of acidic deposition, which has also been steadily declining in eastern North America in recent decades. Deposition of trace metals from the atmosphere (except metalloid mercury) is also expected to be low in the region at present because of the distance of sources such as smelters, incinerators and hydro-electric plants. On the other hand, there is concern about the long-range transport and deposition in surface waters of mercury and persistent organic pollutants including brominated organic compounds, some of which are flame retardants; PCBs (polychlorinated biphenyls); and pesticides. In the atmosphere, many of these chemicals undergo 'cold condensation' when they encounter Arctic fronts and can settle quickly in cold-climate areas such as the Far North. They then move through the bioaccumulation processes that bring them to concentrations that can become toxic to wildlife and human consumers.

Wetlands are considered to be one of the key sites for the formation of water soluble methyl mercury (MeHg) from airborne mercury brought from distant industrial sources like coal-fired power stations. Studies have found a strong correlation between the percent of wetlands in a catchment and the MeHg concentration downstream[40]. Given the very high concentrations of mercury recently found in walleye and northern pike in the Albany River[41], it is very important that this correlation be assessed in the context of the extensive wetlands of the Far North.

To date, the release of potentially toxic metals in industrial effluents is limited because of the very small number of active or abandoned industrial sites. In 2009, Ontario began a six-year cleanup of 16 Mid-Canada Line cold war radar sites in the Far North, abandoned more than forty years ago.

The Centre of Excellence program, ArcticNet[42], provides information about water quality in Hudson Bay estuaries and coastal waters. These highly productive areas are subject to large inputs of suspended sediments, dissolved and particulate carbon (with associated mercury), and nutrients, and can be important systems for migratory fish, such as sea-run brook trout and whitefish.

2.4 PEATLANDS

About a tenth of the globe's cooling benefit from peatlands comes from Ontario's Hudson Bay Lowland[43]. The Hudson Bay Lowland constitutes the second largest peatland complex in the world, only exceeded in size by the western Siberian lowlands. Globally, northern peatlands cover only about 3 to 5% of the Earth's land area but store about 25% of all terrestrial carbon (200 to 600 Pg C)[44]. They are the most dominant landcover type in the Far North (Fig. 8) and, globally, they represent some of its highest carbon densities (Fig. 9), in the order of more than 150 to 200 kg/m^2[45]. By comparison, a typical boreal upland forest or tropical rainforest is unlikely to exceed carbon densities of 75 kg/m^2. The estimates of current carbon accumulation in this region range between ~20 and 30 g Cm^2/ m^{-2} yr^{-1}[46]. At present, the release of carbon dioxide from most wetlands is curtailed by high water levels in peatlands, which limit oxidation. Maintenance of existing water regimes is therefore critical for the protection of carbon stores in these systems.

Figure 8 shows that peatlands and permafrost ecosystems cover more than 50% of the Far North, and over 80% of the Hudson Bay Lowland, a higher proportion of this region than anywhere else in Canada[47]. They vary in peat depth; for example, bogs average 2.2m and, where they are frozen into peat plateaus closer to Hudson Bay, their depth averages more than 3m. Fen peatlands are shallower but still average 1.8m deep[48]. The unparalleled scale and patterns of these interconnected surface waters, wetlands and peatlands attracted scientific attention as early as the 1960s, resulting in research fundamental to the understanding of Canada's wetlands[49].

Peat accumulates over time because annual primary production exceeds its decomposition. Decomposition is severely restricted because the saturated condition of peatlands limits the diffusion of oxygen into the peat and, hence, the bulk of the peat profile is subjected to much less efficient anoxic decomposition. While this process stores carbon, it also leads to the production of methane (CH_4), another powerful greenhouse gas. If the water table in the peatland is close to the surface, or if a peatland is dominated by plants such as sedges that can transport CH_4 through the upper unsaturated–oxic zones of a peatland (where oxidation can occur), then methane emissions from a peatland can range from 2 to 30 g CH_4-C m^{-2} yr^{-1}. Estimates of this process vary, but recent compilations of surface measurements and inverse modelling of atmospheric concentrations of methane indicate that northern peatlands account for ~10% of the total atmospheric burden, and as much of 30% of all natural sources[50].

While peatlands are a net source of methane to the atmosphere, they are an important sink for CO_2. Unlike other terrestrial ecosystems, the large store of biologically sequestered carbon in peatlands is sustained over thousands of years, long after the same systems' methane emissions have equilibrated with atmospheric concentrations of methane. Thus, a portion of the total stored carbon (~20% or ~70 Pg C) can be viewed as avoided atmospheric CO_2. If peatlands are older than 300 to 500 years, as is the case with peatlands in the Far North, then this sequestered C results in a net radiative cooling of the Earth. The peatlands of the Far North store as much carbon as all the other natural ecosystems of Ontario combined, likely more than 35 GtC[51]. Peatlands in the Far North annually sequester an amount of carbon equal to about a third of Ontario's total carbon emissions[52]. Globally, the Hudson Bay Lowland acts as a major carbon reservoir (sink), and any change in its capacity to store carbon, for example through climate warming, may trigger as yet unpredictable atmospheric effects.

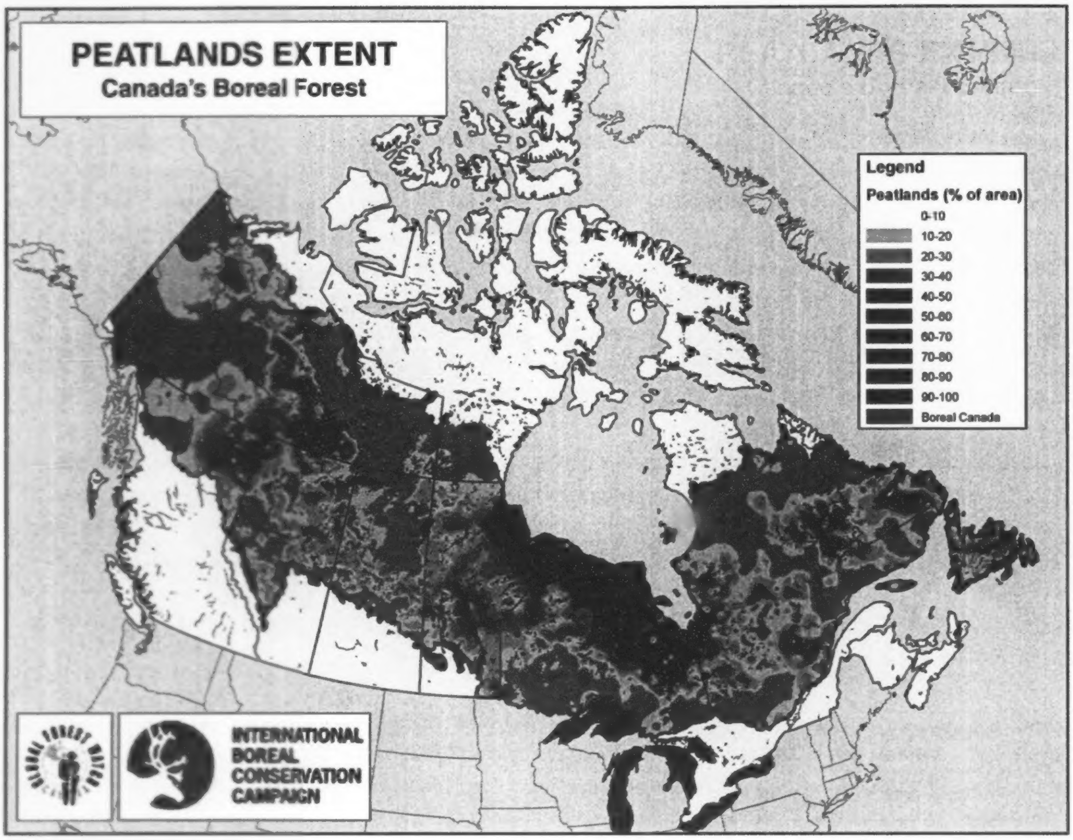


Figure 8. *The extent of peatland cover in Canada. Source: International Boreal Conservation Campaign [www.interboreal.org], adapted from the original diagrams presented in I.M. Kettles and B. Lacelle. 2002. Peatlands of Canada Database. Geological Survey of Canada, Open File 4002.*

The 'two-gas' role of peatlands – as sinks for carbon dioxide (CO_2) but emitters of atmospheric methane (CH_4) – makes them a unique ecosystem. Both greenhouse gases have to be considered as present-day carbon functions of peatlands. CH_4 is a more powerful radiative greenhouse gas than CO_2 but it has a much shorter atmospheric lifetime. Thus, CH_4 is important in the short-term (<100 years) but the CO_2 sink is much more important in the long term (>300–400 years)[53]. At present, peatlands in the Far North are a major net sink of carbon dioxide and a moderate source of methane emissions[54]. From the perspective of both carbon and methane greenhouse gases, the Far North therefore carries with it a global responsibility for conservation, research and modeling of greenhouse gases.

Increases or decreases in peatland water levels will change the storage, sequestration, emission and cooling roles of those systems. Northern ecosystems at the southern limits of permafrost are especially sensitive to climate change because small changes in temperature can have significant effects on snow cover and thaw depth[55]. Palsas, peat plateaus, tundra, ice-aggraded river levees and thermokarst lake

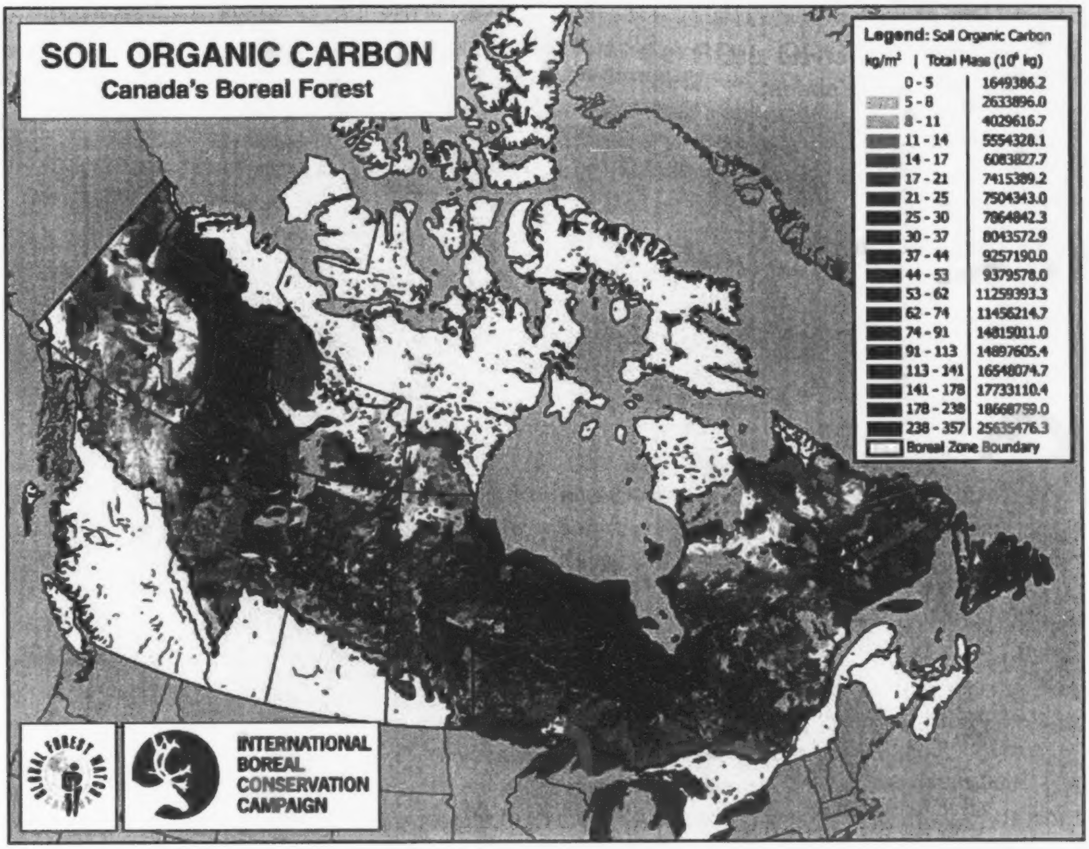


Figure 9. *Soil carbon densities in Canada expressed in kg C/m². Source: Diagram from [www.interboreal.org]; map prepared by Global Forest Watch Canada for the International Boreal Conservation Campaign and the Natural Resources Defence Council; data source: C. Tarnocai and B. Lacelle, Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada.*

systems are particularly susceptible, and both collapse and accretion features are widely visible in the northern Lowland. It is not yet known whether they reflect natural cycles or more unidirectional succession[56]. Climate warming may also draw down water levels in peatlands that do not have permafrost, and melt and erode permafrost peatlands where they exist. It is difficult to predict the implications of these changes for the release of greenhouse gases[57], but clearly the sensitivity of these important systems to water level changes warrants great caution in planning land use where intended development can alter streamflows or peatland water storage.

Fire is a potential issue in peatland systems, especially in a warming climate. The water content of the peatlands is controlled more by local water table than by precipitation and evaporation, so it is unlikely that present predictive indices of fuel moisture and fuel loading, which were designed for forest systems, can be used to predict the fire risk of peatland fuels[58]. Peatlands generally remain wet until the water table drops significantly due to drought, at which time the upper layers of peat begin to dry[59]. Peat can regain its moisture either by a rise of the water table or directly from precipitation. This drying and re-wetting of peat fuels is not well modeled in current predictive indices, and we also have little understanding of peat-fire behaviour following ignition. There is no peat-fuel model in the Canadian Forest Fire Danger Rating System, or Fire Behaviour Prediction System, and no data have been collected to support such modeling. Similar shortcomings of fire-management systems extend to the rock-barren ecosystems that are frequent on the Shield area.

Both in peatlands and in forests, fire can result in mercury emissions to the atmosphere. Annual mercury emissions released by burning Canadian boreal forests could be as high as 30% of industrial emissions; however, in severe fire years the mercury emissions could be as high as 100%[60]. Peatland fire emissions of mercury may be 15 times higher than those from burning boreal forests[61].

2.5 FORESTS

Forests in the Far North serve critical ecosystem functions, providing habitat for its distinctive fish, wildlife and plants, including critical habitat for species and habitats of conservation concern. They mediate ecosystem hydrology and modify local and regional climates. Human impacts on the forests, especially industrial-scale logging, have the potential to substantially disrupt these functions. Approximately two-thirds of the Far North has been identified as having forest cover, but such estimates are based on definitions of 'forest' that include sparsely-treed systems with as little as ten percent tree cover. In the Far North, a latitudinal gradient in tree cover extends from the main boreal forest in the south, through taiga, muskeg and rocklands, north to tundra woodlands nearing Hudson Bay. Much of the region is characterized as having the lowest above-ground biomass of any forested terrestrial ecozone in Canada[62].

The OMNR is currently revising its land-cover mapping for the region, and conducting a Forest Resource Inventory of the extreme southern portion of the Far North, to address the shortfall in basic inventory. Upland boreal forests of greater productivity and economic potential are concentrated in the Boreal Shield part of the region; commercial forest potential has been estimated at only 6 to 7% of the total area of the Far North, concentrated in the southernmost portion of the region[63]. By contrast, there is significantly more productive, more dense, and more accessible commercial forest southward in Ontario, where silvicultural guidelines are already in place to guide harvest practices. Corresponding guidance has yet to be developed for the Far North.

Forest composition is characteristic of the northern boreal forests of Canada, with black spruce the dominant important species, particularly in lowland sites, and white spruce, jack pine, aspen, tamarack and white birch the other important species. Tree growth and forest productivity in most of the region is limited, but all aspects of forest productivity and ecological dynamics remain poorly documented.

Although similar in structure, composition, and diversity to forests elsewhere in the Canadian boreal, the forest landscape of the Far North is of global conservation significance from several perspectives[64]. First, together with adjacent areas of Manitoba (and to some extent Québec) it constitutes the core of the largest single extant block of boreal forest free from large-scale human disturbance anywhere in the world. Given recent increases in logging and fragmentation in other large intact forests such as in Russia and Central Africa, the Far North is currently the second largest contiguous intact forest landscape in the world

(Fig. 10). The characteristic boreal forest-woodland-peatland landscape of the Far North constitutes one of the world's single greatest carbon stocks (Fig. 9). The role of intact boreal forests in mitigating climate

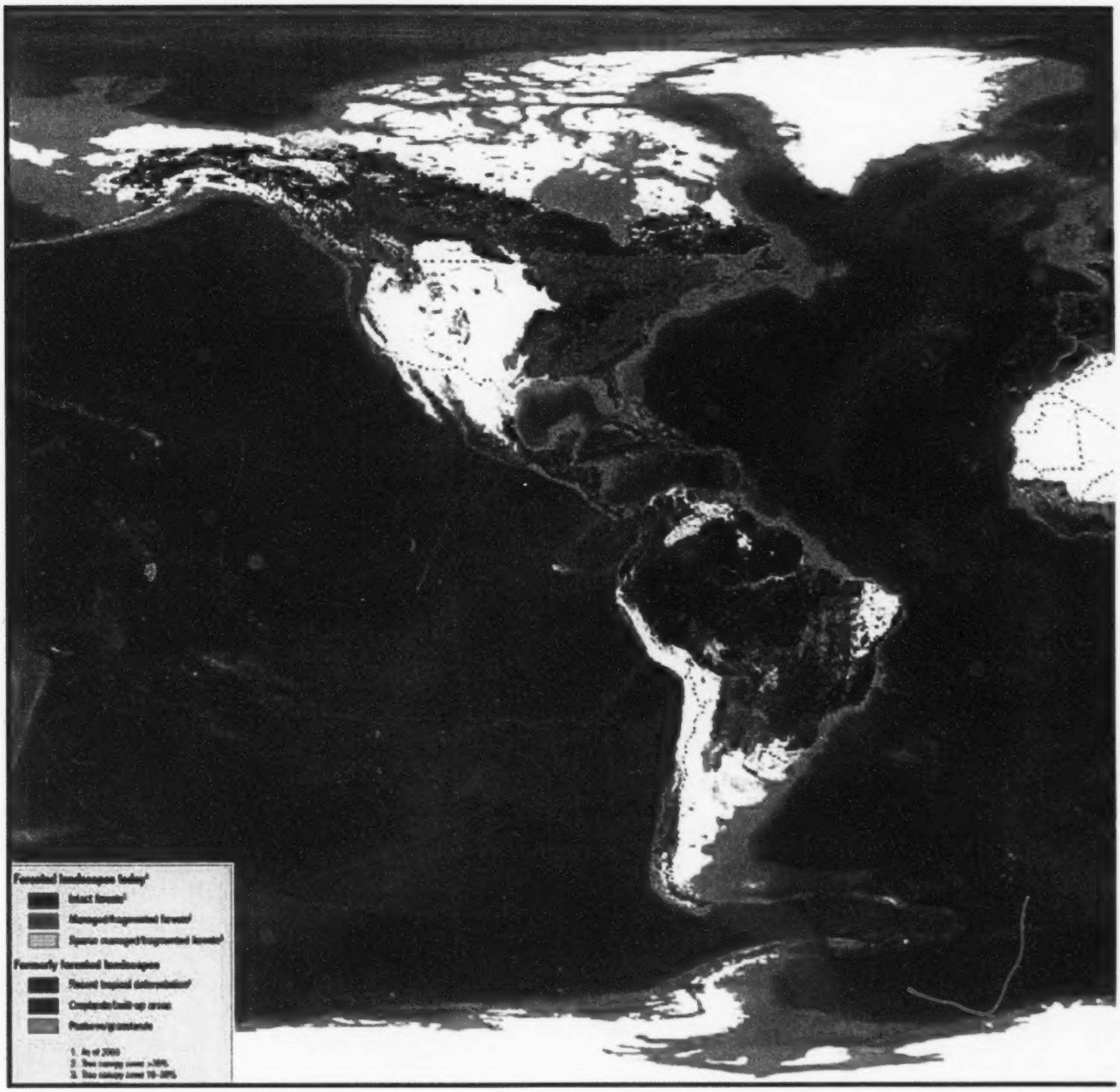
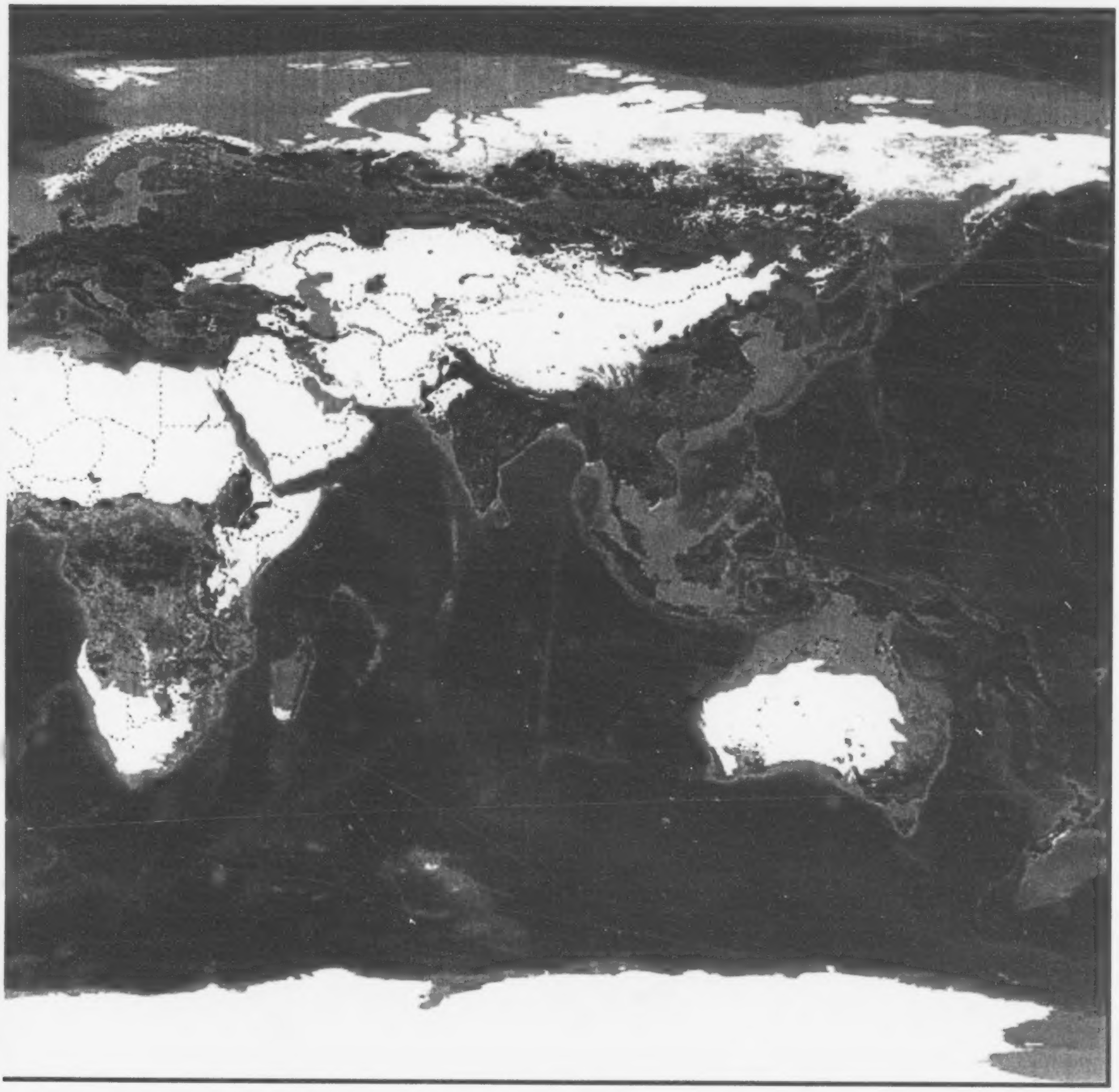

Forested landscapes today
Intact forests
Managed/fragmented forests
Sparse managed/fragmented forests
Formerly forested landscapes
Recent tropical deforestation
Croplands/built-up areas
Pastures/grasslands
1. As of 2000

Figure 10. *World forest landscapes. Source: http://www.wri.org/map/worlds-forests-restoration-perspective. Map and analysis from World Resources Institute (WRI 2009).*

change has generated controversy, and the science remains at a preliminary stage[65]. There is agreement that boreal forests, particularly those on peat soils, serve as carbon stores of global importance, and that



the productivity and net carbon uptake of these systems is slow. There is also agreement that upland boreal forests generally serve as a sink for both carbon dioxide and methane, and that climate change could substantially alter gas flux patterns[66]. Unanswered questions include the response of soil carbon to disturbance, and the net effect of boreal forests on climate, including climate interactions other than carbon flux and storage[67]. A second unresolved issue is the effect of boreal forests on climate via mechanisms other than carbon flux. In general, forested ecosystems have a lower albedo (the ratio of reflected to intercepted radiation) than non-forested areas, an effect that is particularly pronounced for conifer forests during periods of snow-cover. Removal of trees by logging and other disturbances can thus increase albedo and result in a cooling effect that is especially pronounced in boreal forests during winter[68]. At a landscape scale, however, large-scale logging in the boreal does not result in a replacement of boreal forests with grasslands with increased albedo, but rather with young forest stands that have albedo more similar to older stands than to grasslands or tundra. Changes in albedo following forest harvest are clearly complex and their effects on climate require more research[69]. There is also uncertainty regarding forest harvesting impacts on non-CO_2 radiative forcing agents, including methane, nitrous oxide, and volatile organic carbon compounds[70].

The forests of the region are expected to experience significant impacts from global climate change, including changes in species composition and increased extent and duration of wildfires. Minimizing these and other impacts will likely be central to maintaining ecological function and resisting the impacts of climate change, such as by facilitating latitudinal genetic exchange and migration, minimizing increases in fire threat associated with development, and slowing permafrost losses.

2.6 NATURAL DISTURBANCE PROCESSES

Wildfire is a critical ecological process in the Far North, one that can alter and rejuvenate entire landscapes, and significantly threaten the safety of communities. Fires in the Far North are suppressed near communities, although smoke from more distant fires can still be a health threat. Elsewhere in the Far North, away from communities, fires have generally not been suppressed, except in forests along its south boundary.

Figure 11 shows the Far North divided into the Shield and the Hudson Bay Lowland landscapes. During the 13 years spanning 1995-2007, 7.5% of the Shield burned. The comparable burned area in the Lowlands was 1.65%. This indicates an average fire return interval of about 175 and 800 years, respectively. The average annual burned area of the Far North (1980-2007) is about 150,000 ha or about 2.5 times higher than the average annual burned area of the boreal forest immediately south of the Far North, where suppression is the prevalent practice[71].

Historically, the boreal fire season was bimodal, with a peak in late April-May due partly to the lack of green-up. This was followed by a drop in June due to higher rainfall and the arrival of full green-up, and then a gradual drying of the deep organic soil layers through July and August that resulted in another peak in fires in August and early September. Spring fires tended not to burn deeply because of plentiful moisture in the deep organic soil layers following snow-melt and spring rains. Summer fires tended to burn deeper due to increased drying. Since the early 1980s, however, Ontario has experienced more intense spring fires due to a decline in winter snowfall and, sometimes, an absence of spring rainfall. It is not clear if this is a lasting trend but the 1980s and 1990s were the most severe decades for fires. Meanwhile, fire-weather modelling

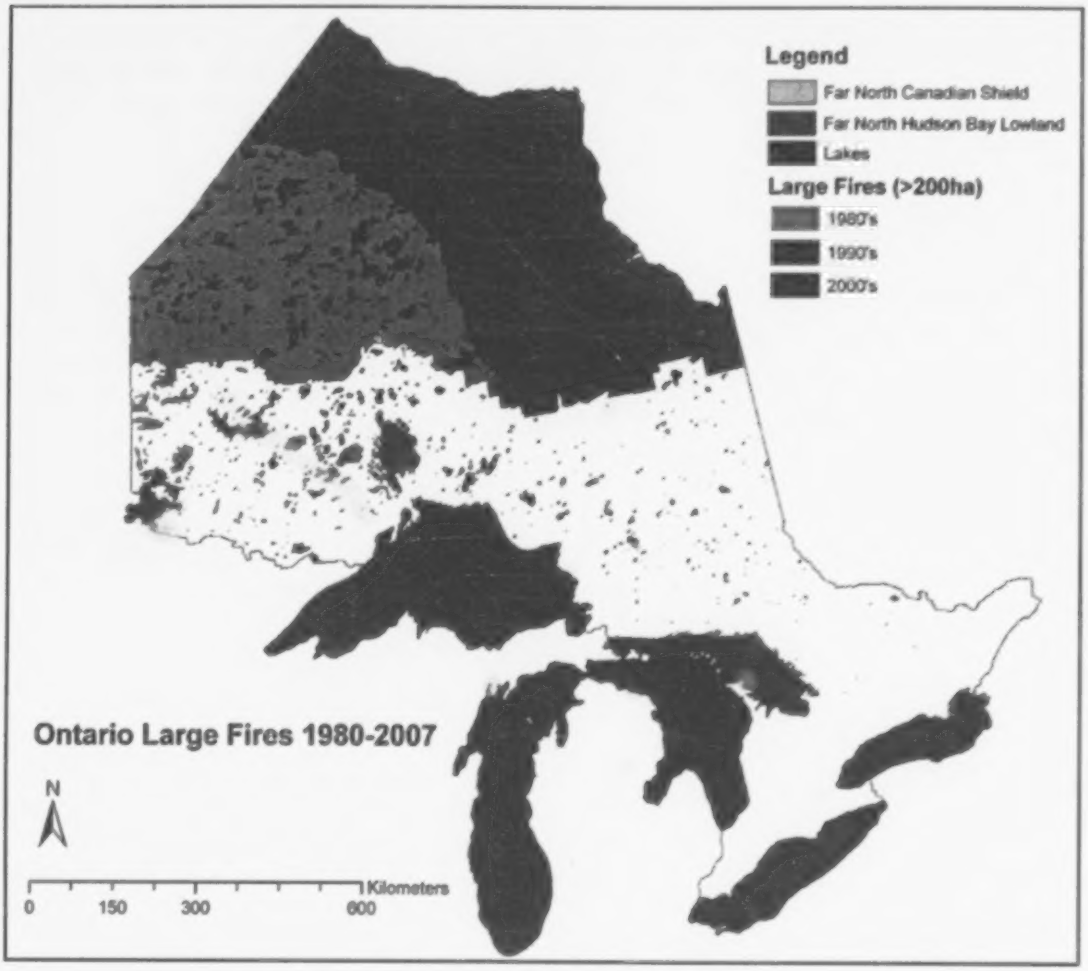

Legend
Far North Canadian Shield
Far North Hudson Bay Lowland
Lakes
Large Fires (>200ha)
1980's
1990's
2000's
Ontario Large Fires 1980-2007
N
0
150
300
600
Kilometers

Figure 11. *Ontario Large Fires (greater than 200 ha) 1980-2007. Source: OMNR fire database for 1980-1994 and NRCan satellite fire mapping database for 1995-2007.*

based on a doubling of pre-industrial CO_2 levels (projected to happen by 2040) suggests a lengthening of the Far North fire season by about 15 days in the spring and 10 days in the fall[72].

Direct human activities can alter the fire regime by changing the fuel landscape and the pattern and frequency of fire ignition, including introducing new sources of ignition. Increased industrial activity will also result in more fires. Climate change is also expected to bring an increase in fire ignitions caused by lightning. As with many other systems in the Far North, a lack of data hinders fire analysis. A denser network of meteorological stations, as well as a network of peatland water-table-monitoring stations, is necessary to support the development of models to predict and manage fire, and to understand the particular behaviour of fire in peatlands. The lack of such monitoring networks also increases the uncertainty of climate-change projections (Fig. 5 illustrates current monitoring networks).

In addition to fire, the natural disturbance regime of forests in the region includes cyclical defoliating insect outbreaks, and natural gap dynamics in areas that escape stand-replacing fires. Although data on aspects of the disturbance regime other than fire are scarce or non-existent, the strong east-west gradient in the frequency of natural fires corresponds to a gradient in the average age of forest stands and other disturbance processes, including insect outbreaks, tree senescence, and gap dynamics, that are likely of greater importance in areas further east in the region[73].

2.7 BIOLOGICAL DIVERSITY

Wildlife remains abundant in the Far North and is of critical importance to its residents, who have made continuous use of it for millennia. During the two centuries of intensive fur-trade, species like beaver, marten, caribou and ptarmigan experienced significant declines, as did some of the migratory birds that bred in, or migrated through, the Far North. Over the past century, however, the populations of furbearers such as beaver and marten have recovered, and some of the region's waterfowl populations continue to expand. Recently, technologies like snowmobiles and all-terrain vehicles have improved access to fish and wildlife. However, for all of this, the Far North still supports populations of wildlife of continental importance, because of its unique character, its marine coast and its relative remoteness. The residents of the region rely on game like moose, caribou and migratory birds, and the fish in its lakes and rivers, and its fur-bearers, far more than anywhere else in Ontario[74].

2.7.1 Mammals

All of the 53 mammal species that migrated into the Far North after the ice sheet melted still occur there; none has been extirpated. These include widespread, larger-bodied species such as beaver, muskrat, gray wolf, red fox, black bear, polar bear, wolverine, marten, mink, otter, lynx, moose, and caribou. White-tailed deer, and fisher are mostly confined to the southern fringe of the Far North. On the Shield, streams and lowland habitats are shaped by beaver activity, and the ponds and wetlands, along with the flora and fauna they support, define much of the region.

Ten of Ontario's mammal species only occur in the Far North, most of them restricted to the Hudson Bay Lowland: arctic fox and northern bog lemming, and a suite of maritime mammals that occur along the coast and in river estuaries – the beluga whale, narwhal, polar bear, walrus, ringed seal and bearded seal[75].

The population of polar bear of southern Hudson Bay is estimated at close to 900[76]. Individuals move between Ontario and the adjacent Nunavut islands and the Québec – Nunavik coast. They rely on the ice of Hudson Bay and James Bay for access to their primary prey (seals), and on coastal lowlands for summer refuge and maternal denning. Polar bear den as far inland as 150 km from the coast. Over the past three decades, although population numbers have remained relatively stable at 4-5% of the global population, there has been a significant decline in body condition, especially among pregnant females and subadults, as well as a decline in longevity of all age and sex classes. These trends suggest that the southern Hudson Bay subpopulation may share the fate of the western Hudson Bay population, which has declined more than a fifth over the past two decades. Polar bear biology has been studied intensively in the past twenty years, and has shown there to be three different breeding clusters among Far North bears. The conservation of polar bear is of great international interest, as is the impact of climate change on Hudson Bay ice, on which the Far North population depends[77].

The Far North supports two types of caribou, the largely sedentary boreal forest ecotype in its southern two-thirds, and the migratory forest-tundra ecotype in the Hudson Bay-James Bay area. The two caribou ecotypes intermingle to some extent in the winter but the forest-tundra caribou gathers to calve along the coast, while the forest-dwelling type is dispersed widely in the interior during calving[78]. Caribou numbers in the Far North are not limited by the availability of habitat that is rich in macrolichens, which is estimated to occur at many times the amount currently in use[79].

There have been varying estimates of caribou numbers in the Far North over the past fifty years but there is no current estimate of forest-dwelling caribou numbers[80]. The most recent estimate (1998) was 2000 forest-dwelling caribou in the Far North[81]. Similarly, there are no estimates of current mortality from hunting. Wolves are considered the primary natural predators of caribou and their numbers depend in part on the availability of other prey (moose and deer). Forest disturbance can increase the abundance of these prey, which in turn leads to increased wolf predation on caribou. Landscape disturbance by fire and anthropogenic activity is therefore a predictor of range loss for caribou.

The estimate of the summer population of the migratory tundra caribou along the Hudson Bay coast was about 3500 in 2008[82], less than an estimated 11,000 a decade ago[83]. Hunting mortality rate has been estimated at up to 10% of the population annually, and there is no legal non-aboriginal hunt in Ontario. Increased motorized access around Lowland communities may have increased hunting pressure. Over the past decade, the tundra caribou has shifted its summer occupation to what remains the most remote part of the Far North, around Cape Henrietta Maria on the eastern Hudson Bay coastline.

2.7.2 Birds

For many migrating shorebirds and waterfowl, the shores and associated mudflats of James Bay and Hudson Bay are the only tidal saltwater habitats between the maritime arctic and the Gulf of St. Lawrence and the Atlantic and Gulf of Mexico. The coastal ecosystems of the Hudson Bay Lowland as a whole provide one of the North America's primary breeding and nursery landscapes for waterfowl and shorebirds. In addition, the migratory corridor along the Hudson Bay and James Bay coasts is of global significance for waterfowl and shorebird migration. Large proportions of the continental populations of Atlantic brant, lesser snow geese and Canada geese make use of these habitats, and the tidal flats in Ontario are of hemispheric importance for at least fourteen species of shorebirds in both the early summer and fall, including the endangered red knot and subarctic specialists such as hudsonian godwit and whimbrel. The funnelling effect of the coastlines of Hudson Bay and James Bay, which concentrates bird numbers spectacularly during fall migration, is one of North America's few remaining examples of its former faunal abundance.

Waterfowl hatched in the Far North are of major cultural and economic importance to First Nations and to hunting and local economies in southern Canada and the United States, both reflecting the region's present remoteness and its lack of disturbance.

Of the 37 waterfowl species present in the Far North, 26 are reasonably abundant. Those with arctic affinities, such as eiders, are in decline, while several others with temperate wintering areas are increasing, such as snow geese and Canada geese. There are about 800,000 breeding adult migratory Canada geese that use the Far North in the summer, as well as an estimated 400,000 giant Canada geese that fly north from the eastern United States and southern Ontario to moult. Snow geese breed along Hudson Bay at three Ontario locations, principally at Cape Henrietta Maria where they number in excess of 300,000, with another 2-3 million migrating through each year. Hundreds of thousands of shorebirds migrate annually through the region.

Wildlife in the Far North is also affected by distant events. An example of this is the increase in numbers of snow geese, Canada geese and other species that has resulted from habitat changes in their wintering and migration areas, which provide them with plentiful farm crops. These high-energy foods are easily procured, such as grain spilled during the harvest of corn, wheat, barley and rice. Legumes and grasses also provide high protein subsidies at important times during migration. The result has been increased survivorship over the winter and increased recruitment of young birds into the breeding population, as well as improved body condition at the time of breeding. A larger number of individuals return to the Far North, where they find unaltered habitats that do not provide similar food subsidies. They exert heavy foraging pressure that removes coastal vegetation, disrupts soils and over-fertilizes shallow ponds. Secondary impacts include erosion and increased salt concentrations. The growth of populations driven by external forces gives no respite to Hudson Bay Lowland coasts, and no time for rejuvenation[84].

Another example of distant events affecting Far North biodiversity is the case of shorebirds. Many shorebird species breed in the Far North but winter in areas from the southern United States to South America, where they depend on rich maritime coasts and grassland-wetlands such as the pampas of Argentina. During migration they rely on rich shoreline marshes on the Atlantic coast, including areas such as the Chesapeake Bay. Species such as red knot depend on the eggs of the horseshoe crab during this migration and, in the last two decades, fishing pressure has reduced the availability of these eggs. As a result, red knot is now critically endangered, having dropped from over 70,000 to fewer than17,000 individuals in less than 10 years. At least a third of the remaining population is present annually in the Far North and there is a high probability that the entire population uses the James Bay coast to gain body condition after breeding and prior to fall migration to South America. Other shorebirds have similar life cycles, and the case of red knot emphasizes Ontario's global responsibility for protecting its coastal estuaries, marshes and mudflats.

Other birds occur in the Far North in numbers that support a global responsibility for their habitat protection, including yellow rail, Nelson's sharp-tailed sparrow, Connecticut warbler, hudsonian godwit, and Smith's longspur. The production of black duck and northern pintail in the Far North is also of continental significance. The Far North is also at the core of North America's primary boreal breeding nursery for landbirds, and Ontario has a continental responsibility for these birds. Events where they winter in the south, however, such as land clearing, land conversion and fire also affect their abundance and survival[85].

In total, there are 190 species of breeding birds in the Far North, of which 46 occur in Ontario only in the Far North. Thirty-five of these are restricted to the Hudson Bay Lowland. Nine of them are regulated Species at Risk.

2.7.3 Fish

The Far North is a 'biodiversity hotspot' for freshwater fish in Canada, with at least 50 species currently known there. The Far North is unique as Canada's only high-diversity area where human impacts remain low[86]. Despite the region's aquatic biological diversity, almost no work has been done on genetic diversity in the Far North, with the exception of a limited number of studies on major sportfish such as lake trout[87]. Given the rapid isostatic rebound of the region and the resulting recent isolation of populations, the Far North is of interest to evolutionary ecologists, despite difficulties in working in the region.

Common species on the Shield are walleye, whitefish, sucker and northern pike (see Fig. 12), while species like brook trout and lake sturgeon are more common in the Lowland. Most of the 50 species of fish in the Far North occur throughout Ontario's north, with only three species (or forms) restricted to the Far North, these being the sea-run brook trout, arctic char and fourhorn sculpin. Non-native fish are almost absent, other than smallmouth bass[88] and rainbow smelt, which were brought into a few lakes and rivers in recent

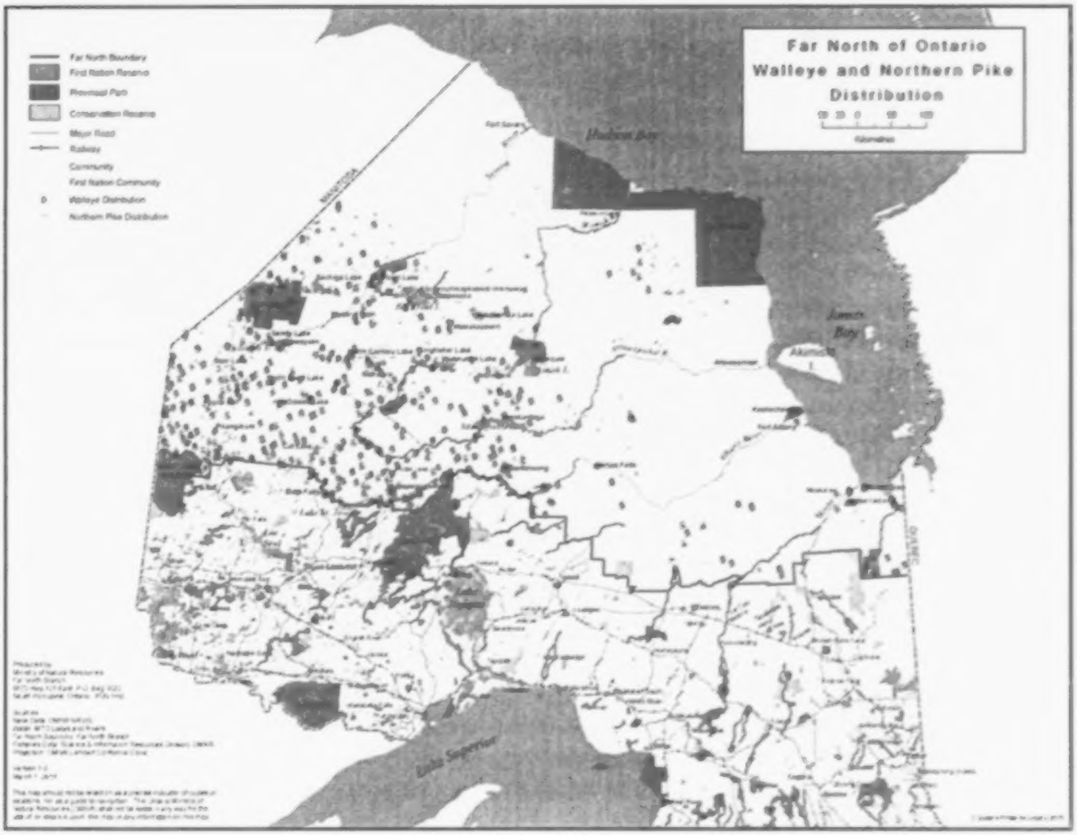


Figure 12. *OMNR's known locations of walleye and northern pike in the Far North, Source: OMNR, 2010. Data exist for a few high-profile populations such as trophy brook trout that migrate from Hudson Bay to spawn in the Sutton River, and lake sturgeon in parts of the Moose River basin. Little or no data exist on marine and estuarine fish along much of the 1200 km-long coastline.*

2.7.3 Fish

The Far North is a 'biodiversity hotspot' for freshwater fish in Canada, with at least 50 species currently known there. The Far North is unique as Canada's only high-diversity area where human impacts remain low[86]. Despite the region's aquatic biological diversity, almost no work has been done on genetic diversity in the Far North, with the exception of a limited number of studies on major sportfish such as lake trout[87]. Given the rapid isostatic rebound of the region and the resulting recent isolation of populations, the Far North is of interest to evolutionary ecologists, despite difficulties in working in the region.

Common species on the Shield are walleye, whitefish, sucker and northern pike (see Fig. 12), while species like brook trout and lake sturgeon are more common in the Lowland. Most of the 50 species of fish in the Far North occur throughout Ontario's north, with only three species (or forms) restricted to the Far North, these being the sea-run brook trout, arctic char and fourhorn sculpin. Non-native fish are almost absent, other than smallmouth bass[88] and rainbow smelt, which were brought into a few lakes and rivers in recent

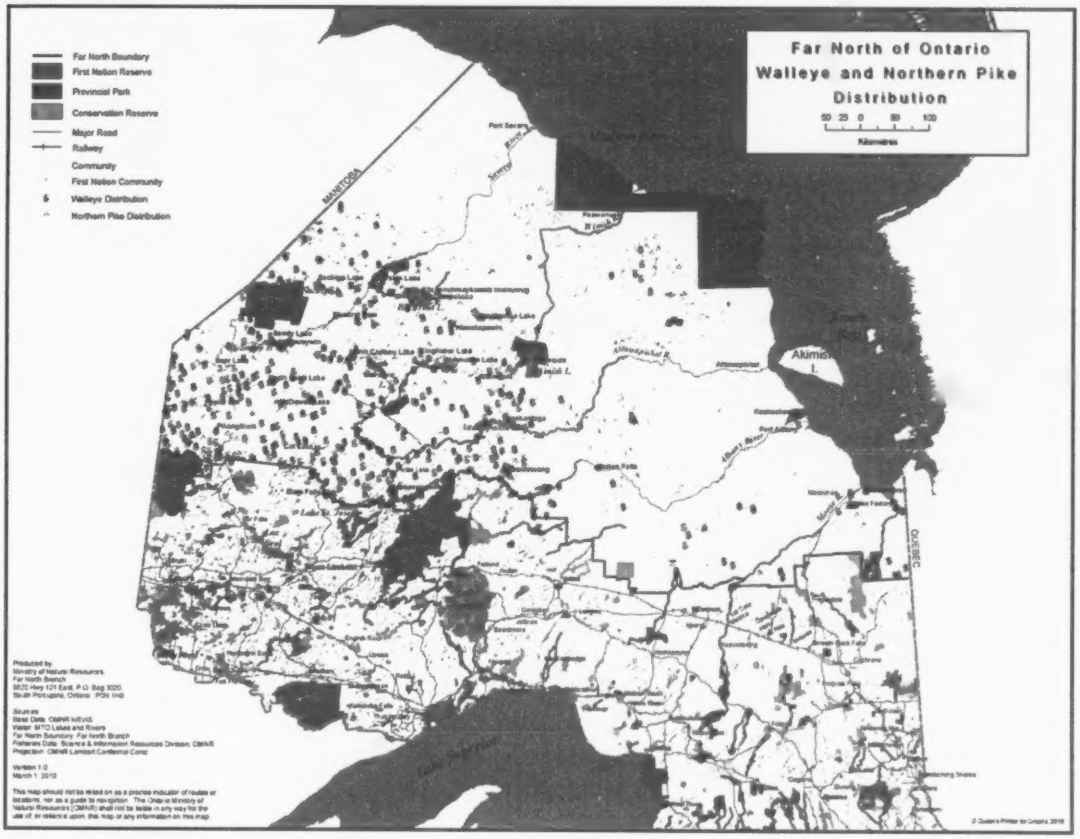


Figure 12. *OMNR's known locations of walleye and northern pike in the Far North, Source: OMNR, 2010. Data exist for a few high-profile populations such as trophy brook trout that migrate from Hudson Bay to spawn in the Sutton River, and lake sturgeon in parts of the Moose River basin. Little or no data exist on marine and estuarine fish along much of the 1200 km-long coastline.*

decades. Generally speaking the extent and quality of fish survey information is much greater for the Shield, where pressures to develop remote tourism are likely to be greatest. By contrast, data are available only for a handful of lakes in the Lowlands. Large deep lakes are rare in the lowland, and most of the fishery resources of the Lowlands are found in rivers and estuaries.

Data exist for a few high-profile populations such as trophy brook trout that migrate from Hudson Bay to spawn in the Sutton River[89] , and lake sturgeon in parts of the Moose River basin[90]. Little or no data exist on marine and estuarine fish along much of the 1200km-long coastline.

Lake sturgeon is the only fish in the Far North that has had its conservation status assessed. It is listed as a species of Special Concern in the Far North while southern populations are Threatened. Sturgeon are large and long-lived fish unique to northeast North America, preferring unfragmented rivers and fast waters, such as below waterfalls, making the species susceptible to river and hydro development. They mature late and grow slowly. All sturgeon species are regulated under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and the recreational and commercial fishery for lake sturgeon was closed in Ontario in 2009[91].

Most of the fishing in the Far North is for subsistence, localized around communities. Surveys of coastal communities in the 1990s showed an annual harvest of 400g of wild meat per adult per day, a large part of which was fish[92]. Lake whitefish and cisco (also called herring) comprise a major part of the harvest, particularly along coastal rivers. Commercial First Nation fisheries were active before the 1980s in the larger Shield lakes and in some Lowland rivers (early 1900s), and they had lower harvest levels than elsewhere in Ontario. Tourism fishing is now the main focus of more than a dozen major base lodges and more than 150 fly-in camps, with very few of them operated by residents of the region.

The introduction of alien invasive species as live bait is also a very real threat to the fisheries of the Far North. Climate change impacts are likely to include expansion of competitive warm water species[93], seasonal die-off of migratory species such as brook trout as they enter warm water (already documented as they entered the warm Sutton River in 2001[94]) and increased temperature-related methylation of mercury that accumulates in larger predatory fish.

2.7.4 Species and Spaces of Conservation Concern

In the 1970s, the International Biological Program documented sites of conservation interest known to scientists of the day. Similarly, since the 1970s, OMNR programs have been charged with compiling a provincial inventory of significant natural areas representative of the earth science and live science diversity of Ontario (areas of natural and scientific interest) (Fig. 13). Other sites of historic, cultural and archaeological concern have been identified by programs in the Ontario Ministries of Natural Resources (1970s and 1980s) and Culture (1990s to present), and are maintained in agency data bases. Many other areas of special conservation concern are also known to communities and individuals in the Far North.

Current data suggest that the Far North supports a number of federal and provincial-listed endangered and threatened species, and species of concern. These are listed below in table form, and mapped in Figure 14. A number of other species are considered provincially rare, not occurring in more than 100 locations in Ontario (S1-3). Ontario's Biodiversity Strategy (2005) identifies goals and strategies to protect the full diversity of Ontario species and ecosystems.

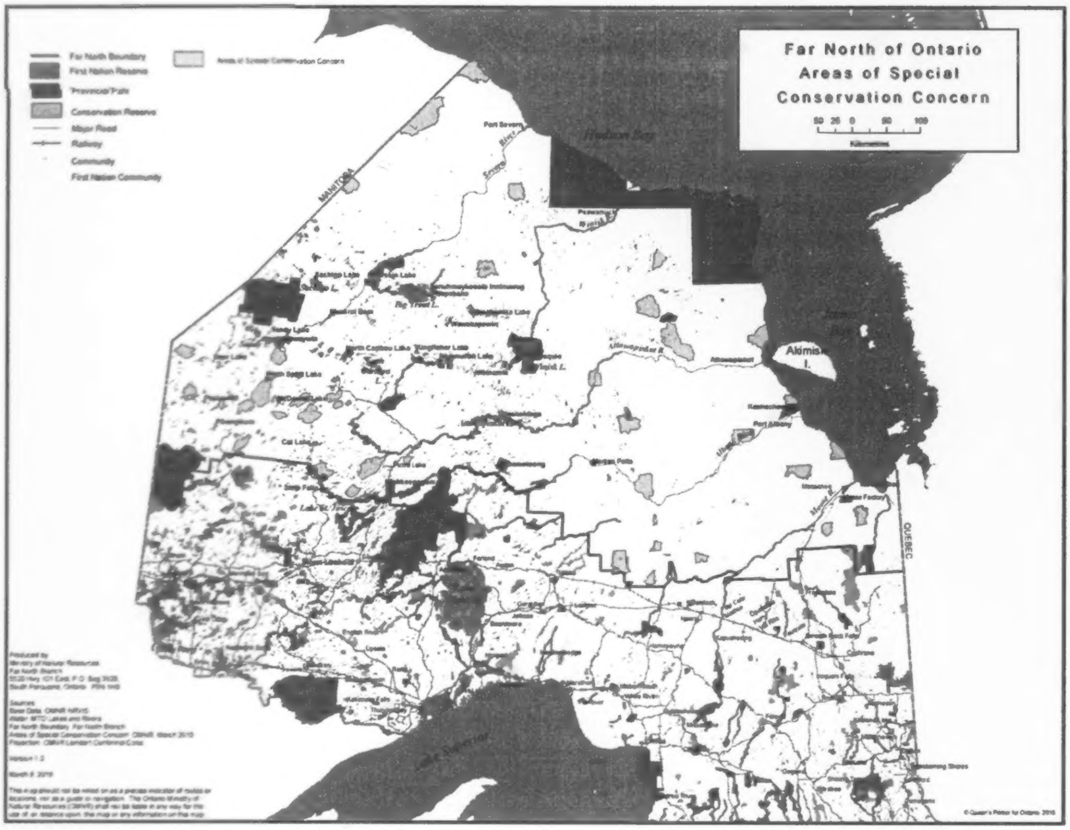


Figure 13. *OMNR's known locations of areas of conservation concern. Source: OMNR, 2010.*

Several other designations point to portions of the Far North of particular conservation interest. Two RAMSAR Wetlands of International Importance have been identified in the Far North; one is (the whole of) Polar Bear Park (1987), and the other is the southern James Bay coast (1987). An early conservation interest in the region was associated with the waterfowl and shorebirds along James Bay. Two national migratory bird sanctuaries were established as a result, at Hannah Bay (1939) and the mouth of the Moose River (1958) (Fig. 13). The Important Bird Areas (IBA) program identifies the network of sites worldwide that are necessary to ensure the long-term viability of bird populations. In the Far North, the documented IBAs all occur in the Hudson Bay Lowland, seven of them on the Hudson Bay coast, and eleven of them along the James Bay coast. (Fig. 15).

There are at least 150 species of plants that occur in Ontario only in the Far North. Almost all of these are restricted to the Hudson Bay Lowland, and many of them are rare species at the southern edge of their global ranges. Among them are those occurring only on the arctic tundra along Hudson Bay (55); only in the northern Lowland (54); only at Cape Henrietta Maria (8), only on the Sutton Ridges (3), and only along the southwest James Bay coast (about a dozen); as well as dozens of salt-loving species that occur along the coasts[95].

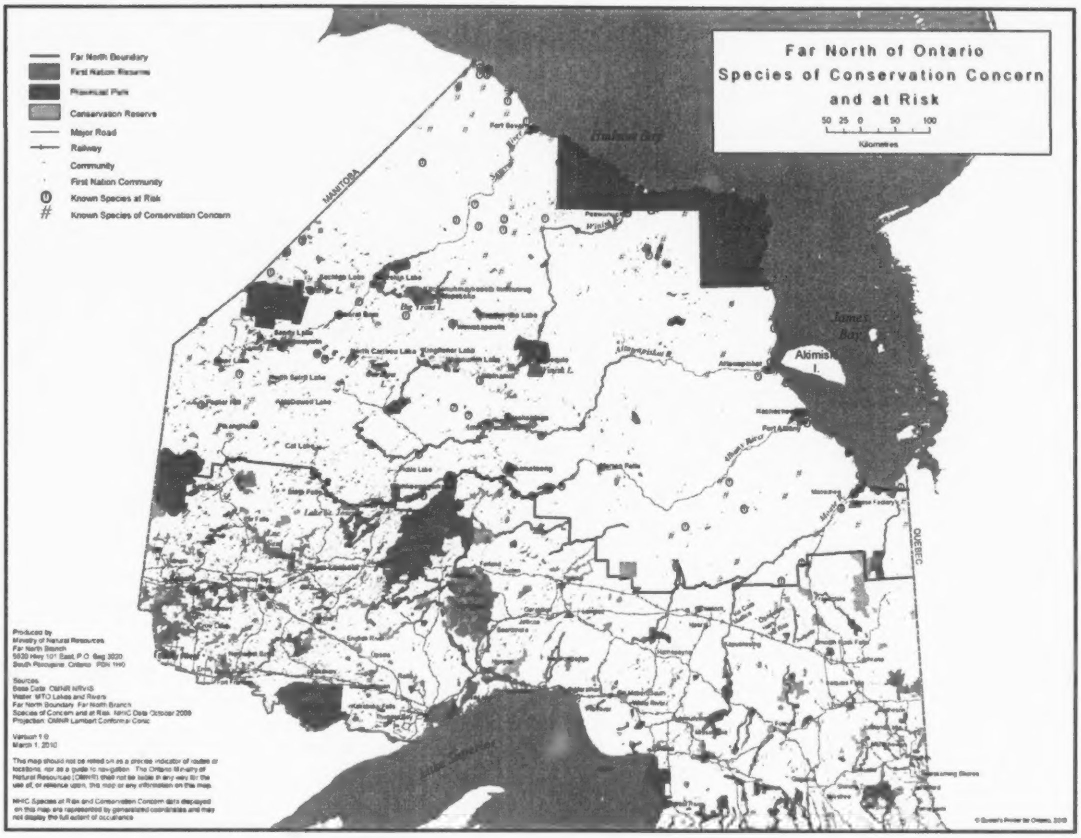


Figure 14. *OMNR's known locations for species of conservation concern and Species at Risk in the Far North of Ontario (data up to 2009). Source: OMNR, 2010.*

The region has twelve provincial parks. Of these, the largest are Polar Bear Park, Canada's largest provincial park, located on Hudson Bay and James Bay, and extending up to 100km inland (established in 1970); and Opasquia, another wilderness park on the Shield near the Manitoba border. Both parks are remote, and full traditional uses are pursued in them by residents and others. Tidewater (Moose River) and Kesagami are two other Far North parks, and there are eight waterway parks along its rivers, most of them partial waterways.

Finally, there are nine species of amphibians and reptiles in the Far North, none restricted only to that region. There have been few if any studies of insects in the Far North.

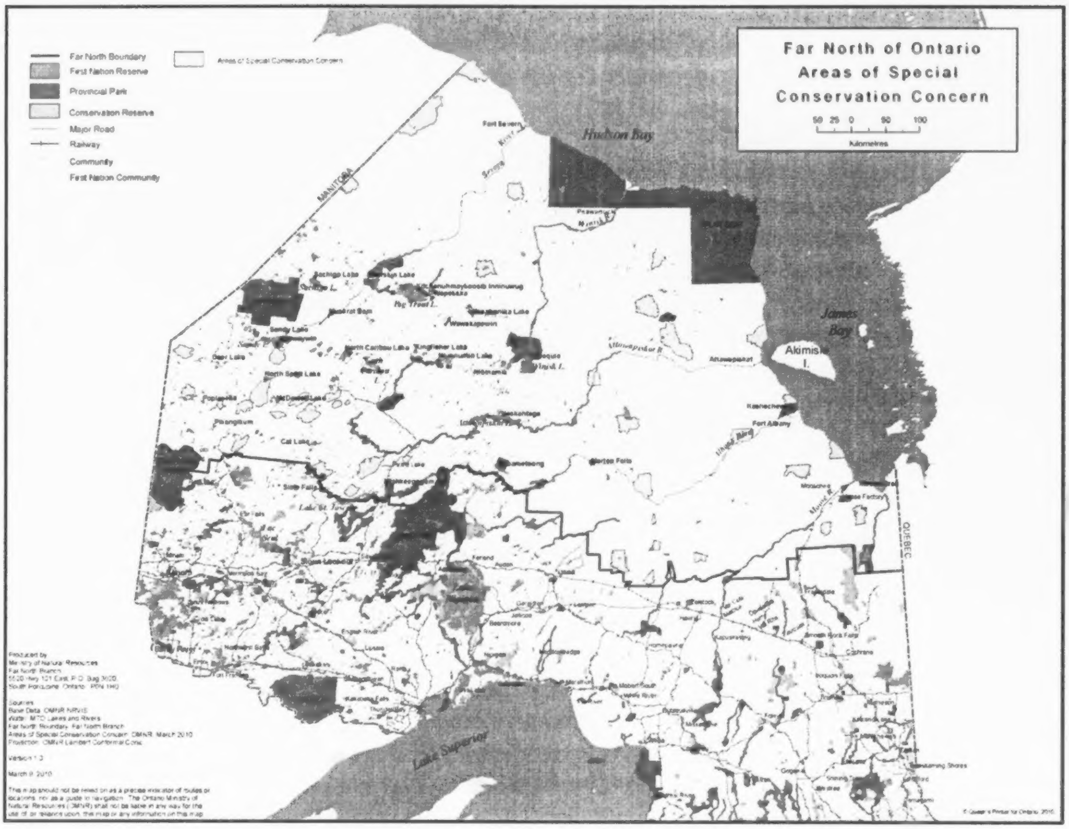


Figure 13. *OMNR's known locations of areas of conservation concern. Source: OMNR, 2010.*

Several other designations point to portions of the Far North of particular conservation interest. Two RAMSAR Wetlands of International Importance have been identified in the Far North; one is (the whole of) Polar Bear Park (1987), and the other is the southern James Bay coast (1987). An early conservation interest in the region was associated with the waterfowl and shorebirds along James Bay. Two national migratory bird sanctuaries were established as a result, at Hannah Bay (1939) and the mouth of the Moose River (1958) (Fig. 13). The Important Bird Areas (IBA) program identifies the network of sites worldwide that are necessary to ensure the long-term viability of bird populations. In the Far North, the documented IBAs all occur in the Hudson Bay Lowland, seven of them on the Hudson Bay coast, and eleven of them along the James Bay coast. (Fig. 15).

There are at least 150 species of plants that occur in Ontario only in the Far North. Almost all of these are restricted to the Hudson Bay Lowland, and many of them are rare species at the southern edge of their global ranges. Among them are those occurring only on the arctic tundra along Hudson Bay (55); only in the northern Lowland (54); only at Cape Henrietta Maria (8), only on the Sutton Ridges (3), and only along the southwest James Bay coast (about a dozen); as well as dozens of salt-loving species that occur along the coasts[95].

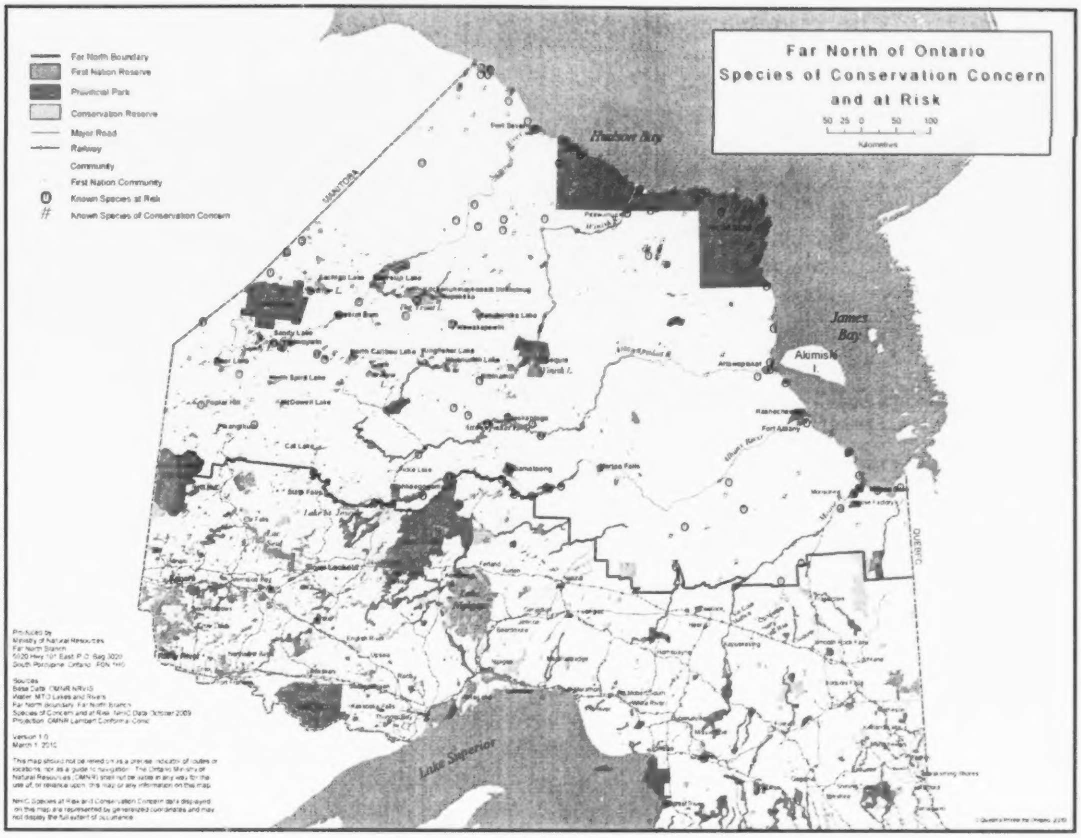


Figure 14. *OMNR's known locations for species of conservation concern and Species at Risk in the Far North of Ontario (data up to 2009). Source: OMNR, 2010.*

The region has twelve provincial parks. Of these, the largest are Polar Bear Park, Canada's largest provincial park, located on Hudson Bay and James Bay, and extending up to 100km inland (established in 1970); and Opasquia, another wilderness park on the Shield near the Manitoba border. Both parks are remote, and full traditional uses are pursued in them by residents and others. Tidewater (Moose River) and Kesagami are two other Far North parks, and there are eight waterway parks along its rivers, most of them partial waterways.

Finally, there are nine species of amphibians and reptiles in the Far North, none restricted only to that region. There have been few if any studies of insects in the Far North.

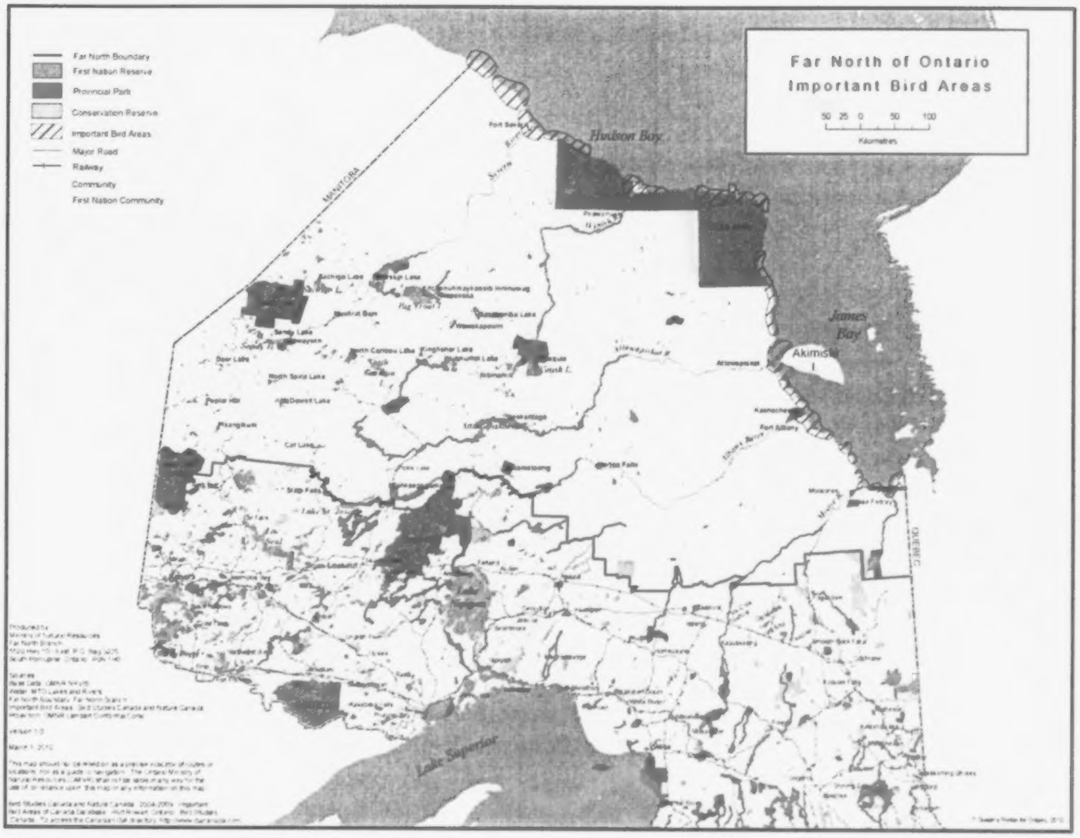


Figure 15. *Documented Important Bird Areas in the Far North. Source: OMNR, 2010.*

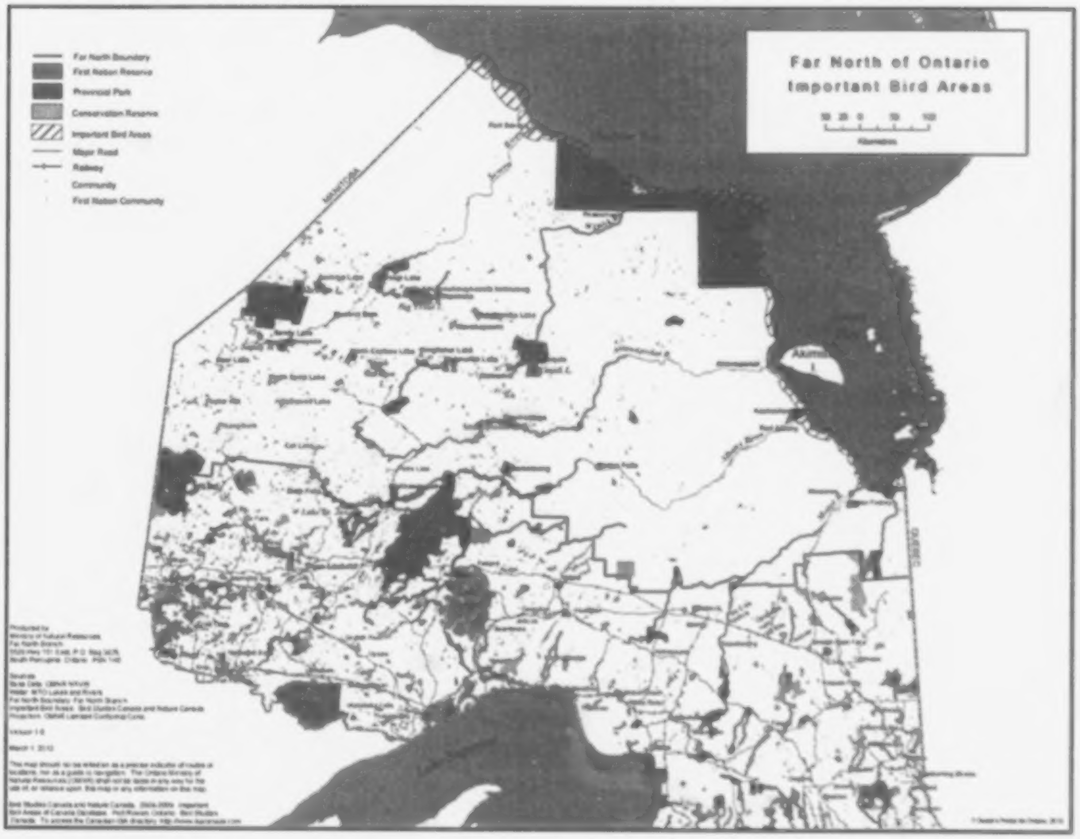


Figure 15. *Documented Important Bird Areas in the Far North. Source: OMNR, 2010.*

3.0

KEY MANAGEMENT ISSUES

3.0 KEY MANAGEMENT ISSUES

In this section we examine the key management issues in the Far North that will affect the region's biodiversity and ecological functions, including ecosystem carbon services. Section 3.1 discusses the external driver of climate change. Climate change will be imposed on the Far North regardless of what else occurs there, but management policies and practices in the region must consider that the natural environment in coming decades may be considerably different from today. In section 3.2, we discuss a second set of drivers – changes that would occur from actions taken in the Far North and that can be managed to minimize or prevent the loss of biodiversity and/or ecological function.

3.1 CLIMATE CHANGE

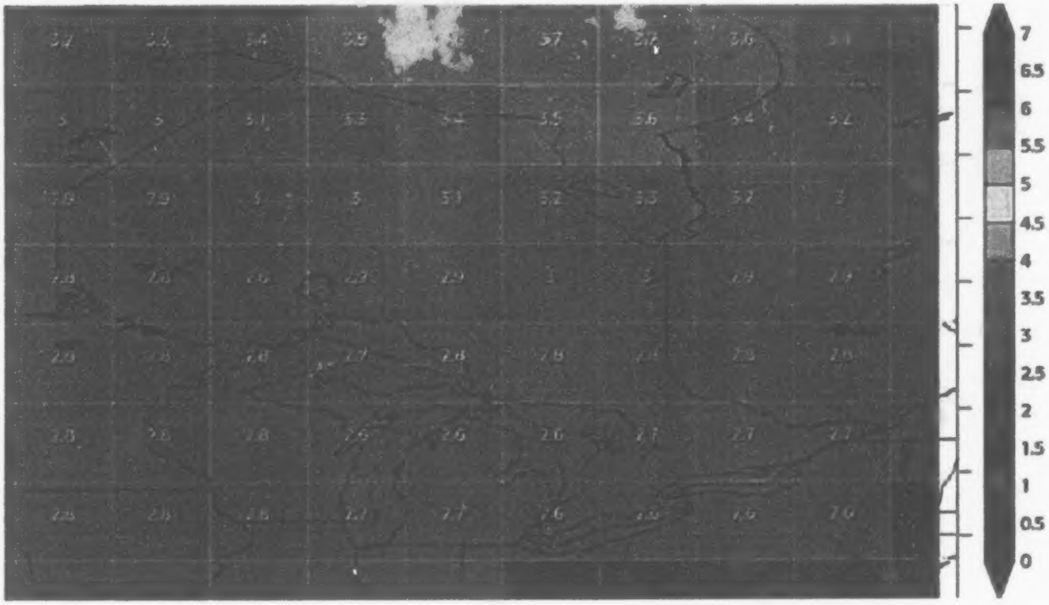
The present-day climate and the attributes derived from the climatic conditions such as the distribution of permafrost, the general hydrology, and the broad scale biogeography of biomes and ecosystems were reviewed in Chapter 2. This section synthesizes the projections for a change in climate over the next 30 to 50 years for the region. The sources of information used to prepare the following assessment for the Far North are Colombo et al. *Climate Change Projections for Ontario*[96] and the ensemble scenarios for future climate change for Canada prepared by the Climate Impacts and Adaptation Research Division (CIARD), Environment Canada. (The ensemble scenarios can be found at *http://www.cccsn.ca/index-e.html*.)

The Colombo report bases its analysis on the Canadian Coupled Global Circulation Model (CGCM2)[97] for three time periods (2011 - 2040; 2041 – 2070; and 2071 – 2100) for two different (A2 and B2) emissions scenarios. The A2 scenario is a higher emissions scenario that results in atmospheric concentrations of 1,320 ppmv CO_2 by the end of the 21st century, while the B2 scenario is a more conservative scenario with end of century concentrations reaching 915 ppmv. The emissions scenarios were prepared by the Intergovernmental Panel on Climate Change (IPCC) based on varying assumptions of population growth, technological development, energy efficiency, international cooperation, and increasing general state of human well-being[98]. Colombo et al. took the output from the CGCM2 and interpolated to a higher spatial resolution. The CIARD ensemble analysis used the outputs of 25 models in the fourth assessment report (AR4) of the IPCC[99].

Coupled carbon – climate models show that terrestrial and oceanic carbon feedbacks could add 20 to 240 ppmv of atmospheric CO_2[100] by 2100. Other recent simulations that include permafrost predict extensive thawing of permafrost and a deepening of the annual active layer depths[101] by the end of the 21st century, but these models are in the early stages and are very sensitive to assumptions of heat transfer in organic soils. The inclusion of cold region processes and organic soils in recent modeling developments is very relevant to the Far North given the very high carbon densities on the landscape. Further, the models that include both permafrost and sea ice indicate that a reduction of the extent and duration of sea ice can have a profound effect on the warming of the terrestrial landscape and this effect can penetrate hundreds of kilometres inland from the Arctic ocean coast[102]. All of these factors – permafrost thawing and deepening of the active layer depths, and reduction of sea ice extent and duration – have the potential to alter the projections shown in this section substantially. On balance, the expectation is that all three factors would result in positive feedbacks – i.e., would enhance the degree of climate change.

It is also important to note the clear evidence that even the high emission scenarios used in the AR4 climate assessments are, at present, too conservative. The actual increase in emissions over the first decade of the 21st century has been between 2 and 2.5 ppm/yr, while the most extreme emission scenarios assumed increases of approximately 1.5 ppm/yr[103]. Given those numbers, the change projected for 2050 under moderate emissions (Figs. 16 and 17) and even high emissions (Table 3) may be exceeded.

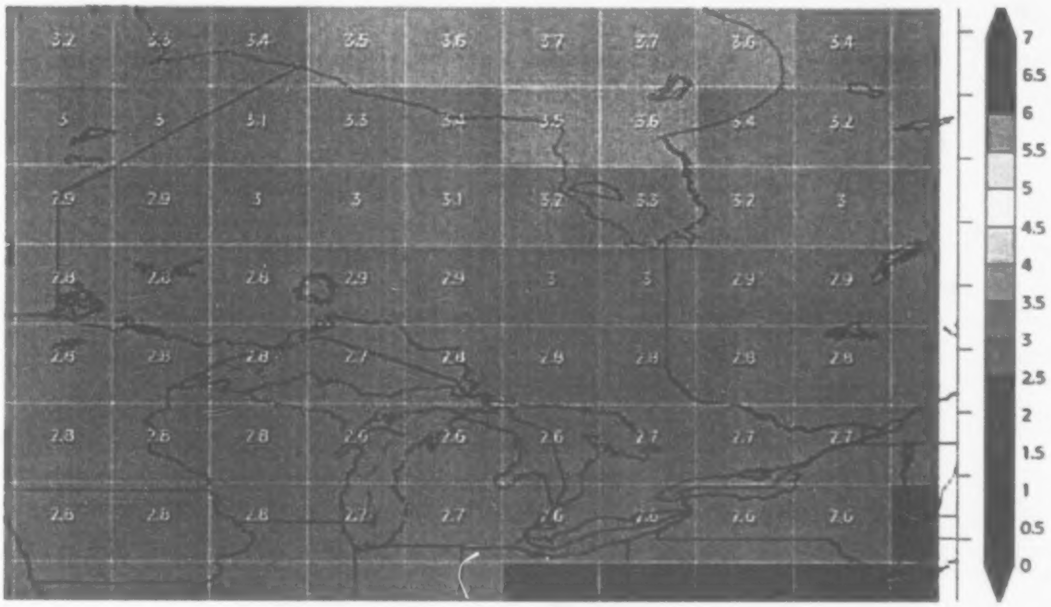
Projected increase (0°C) in average annual temperature in the 2050s



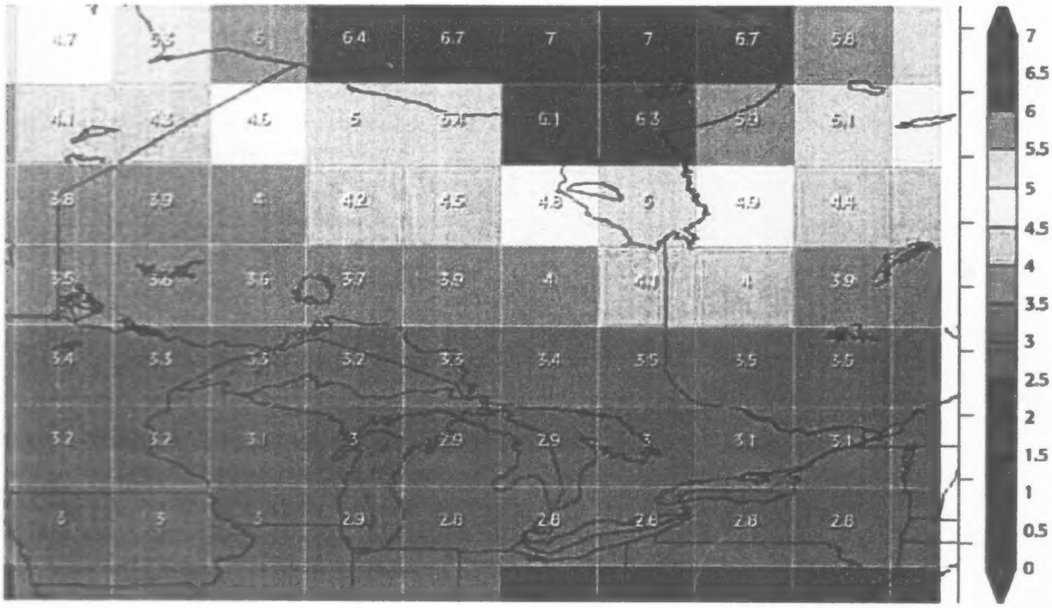
ppmv of atmospheric CO_2[100] by 2100. Other recent simulations that include permafrost predict extensive thawing of permafrost and a deepening of the annual active layer depths[101] by the end of the 21st century, but these models are in the early stages and are very sensitive to assumptions of heat transfer in organic soils. The inclusion of cold region processes and organic soils in recent modeling developments is very relevant to the Far North given the very high carbon densities on the landscape. Further, the models that include both permafrost and sea ice indicate that a reduction of the extent and duration of sea ice can have a profound effect on the warming of the terrestrial landscape and this effect can penetrate hundreds of kilometres inland from the Arctic ocean coast[102]. All of these factors – permafrost thawing and deepening of the active layer depths, and reduction of sea ice extent and duration – have the potential to alter the projections shown in this section substantially. On balance, the expectation is that all three factors would result in positive feedbacks – i.e., would enhance the degree of climate change.

It is also important to note the clear evidence that even the high emission scenarios used in the AR4 climate assessments are, at present, too conservative. The actual increase in emissions over the first decade of the 21st century has been between 2 and 2.5 ppm/yr, while the most extreme emission scenarios assumed increases of approximately 1.5 ppm/yr[103]. Given those numbers, the change projected for 2050 under moderate emissions (Figs. 16 and 17) and even high emissions (Table 3) may be exceeded.

Projected increase (0°C) in average annual temperature in the 2050s



Projected increase (0°C) in average annual winter temperature in the 2050s



Projected increase (0°C) in average summer temperature in the 2050s

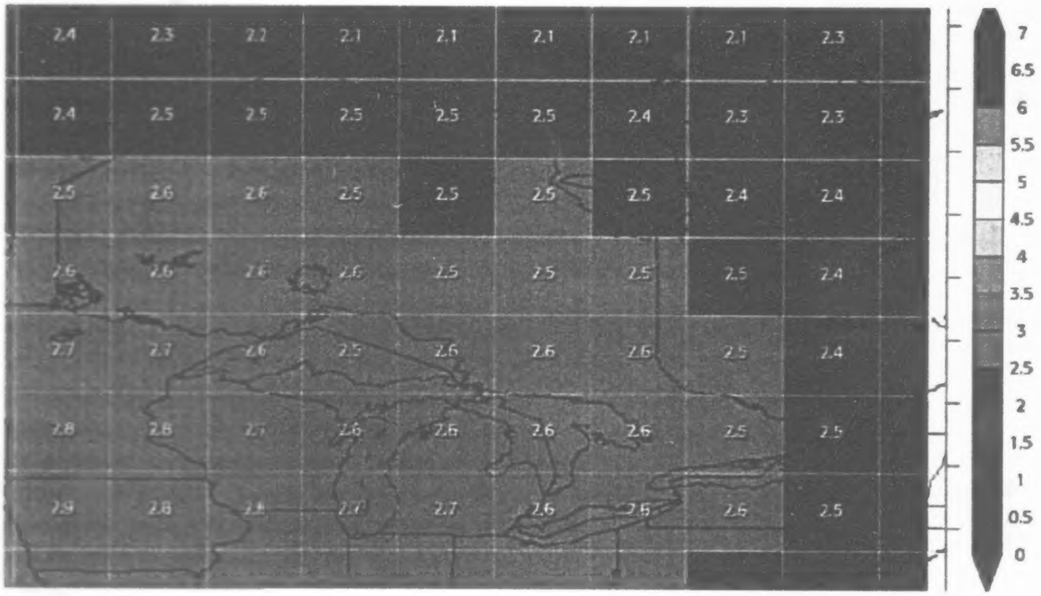
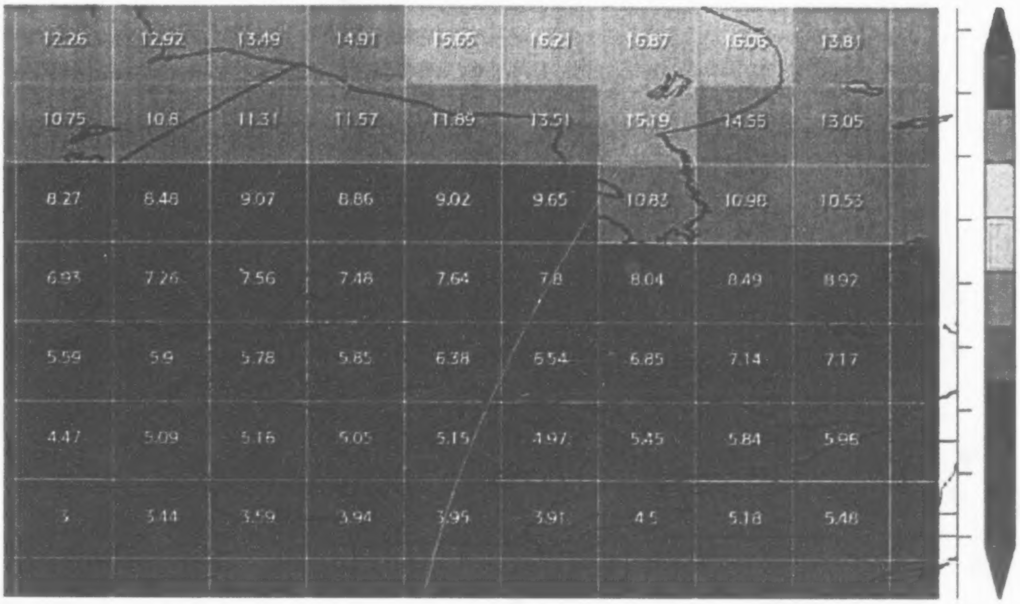
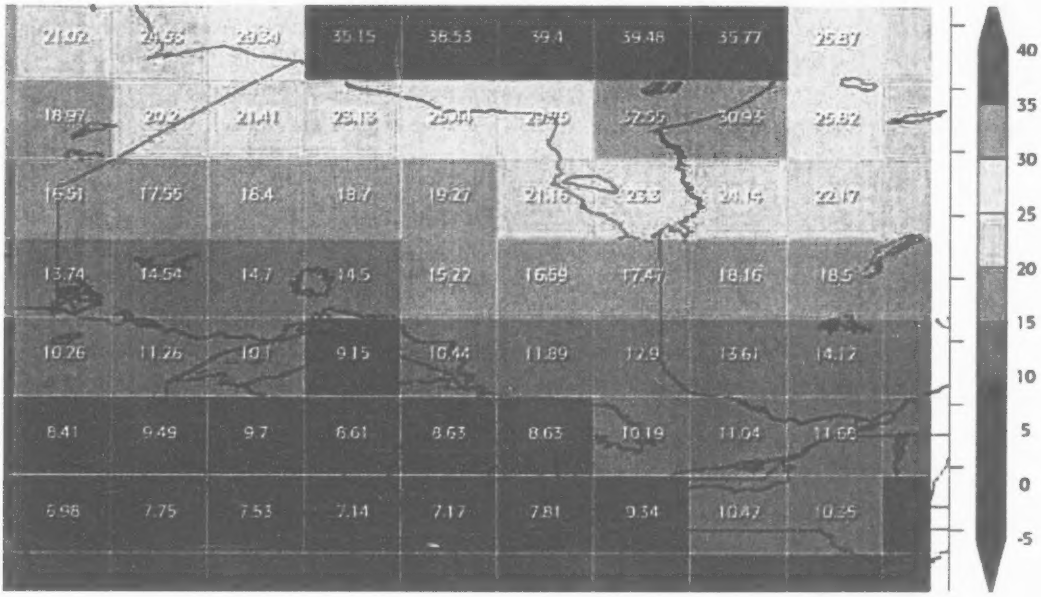


Figure 16. *Ensemble scenarios of projected 2050 temperature change relative to the 1961 – 1990 mean under moderate greenhouse gas emissions. Images obtained from the Canadian Climate Change Scenarios Network website (http://www.cccsn.ca/ensemblescenarios/ensembles-e.html)*

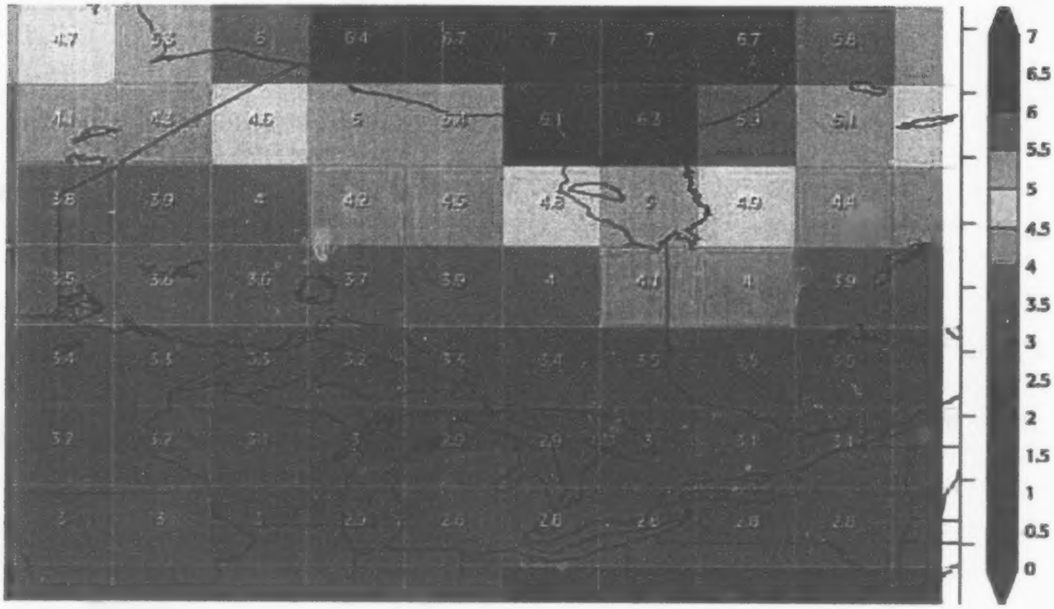
Projected percent change in average annual precipitation in the 2050s



Projected percent change in average winter precipitation in the 2050s



Projected increase (0°C) in average annual winter temperature in the 2050s



Projected increase (0°C) in average summer temperature in the 2050s

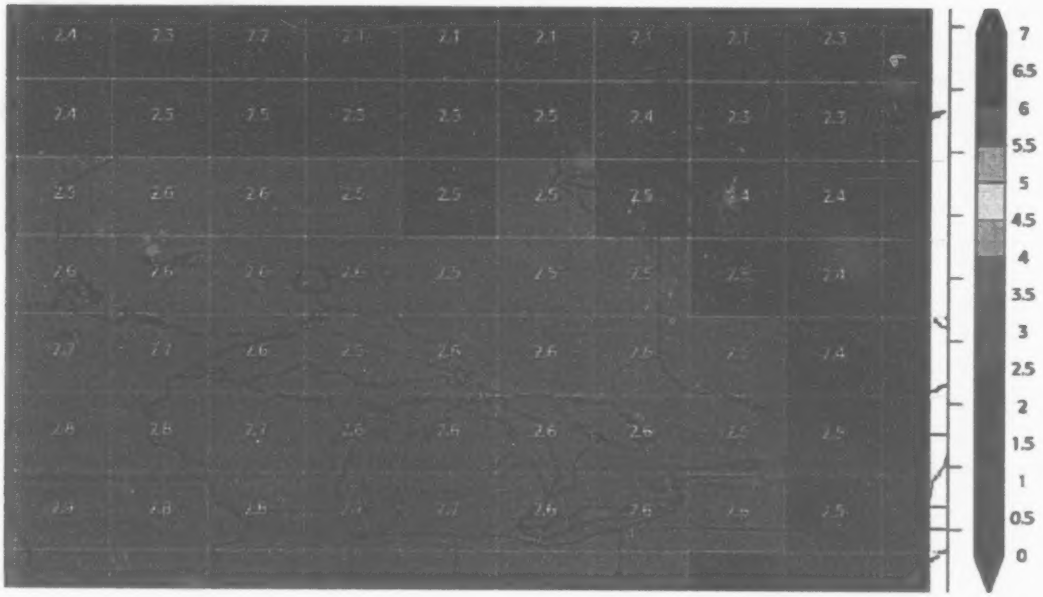
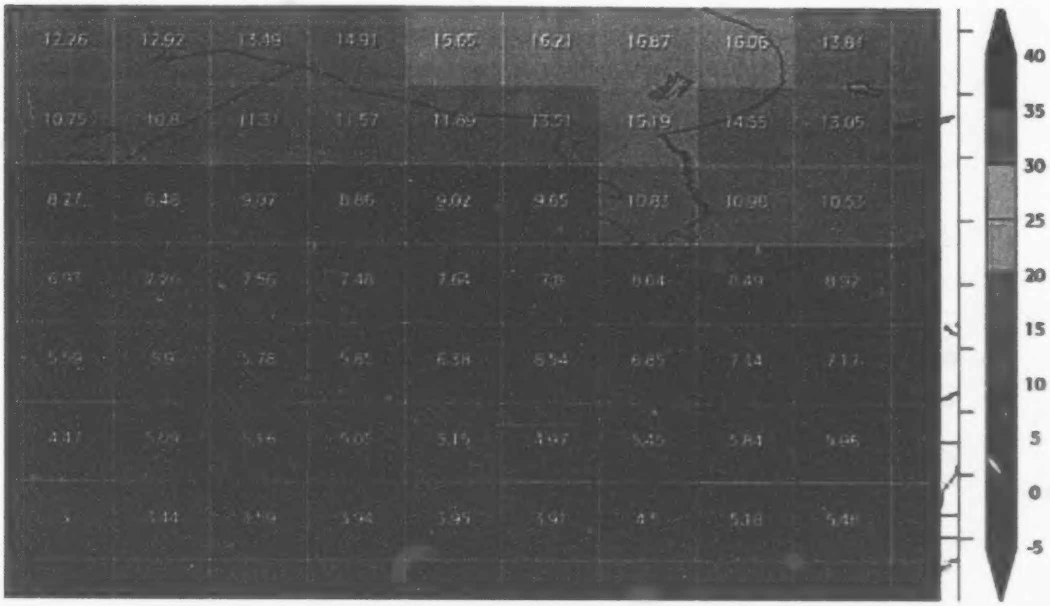
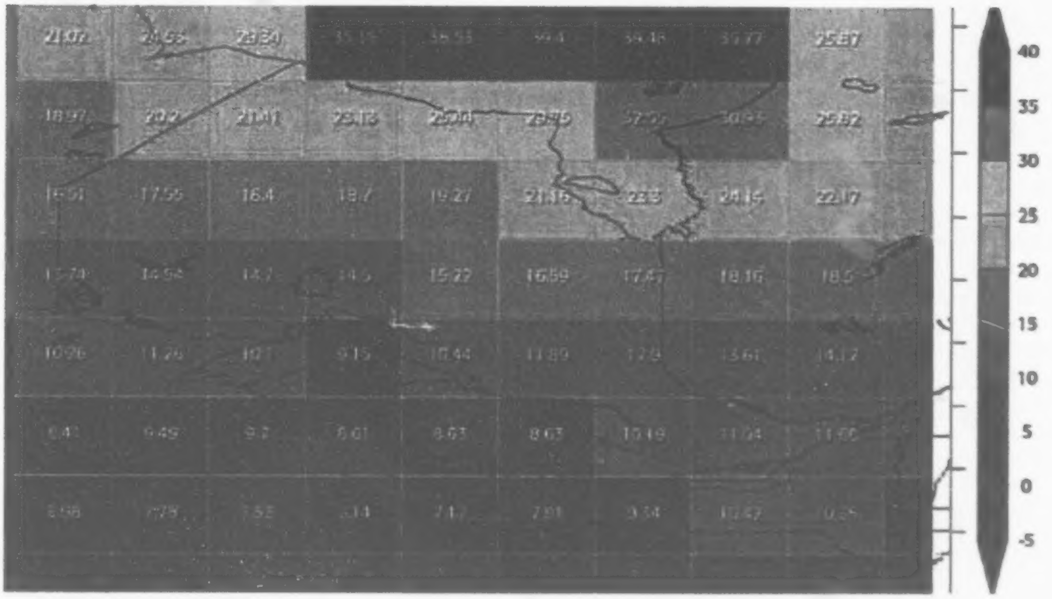


Figure 16. *Ensemble scenarios of projected 2050 temperature change relative to the 1961 – 1990 mean under moderate greenhouse gas emissions. Images obtained from the Canadian Climate Change Scenarios Network website (http://www.cccsn.ca/ensemblescenarios/ensembles-e.html)*

Projected percent change in average annual precipitation in the 2050s



Projected percent change in average winter precipitation in the 2050s



Projected percent change in average summer precipitation in the 2050s

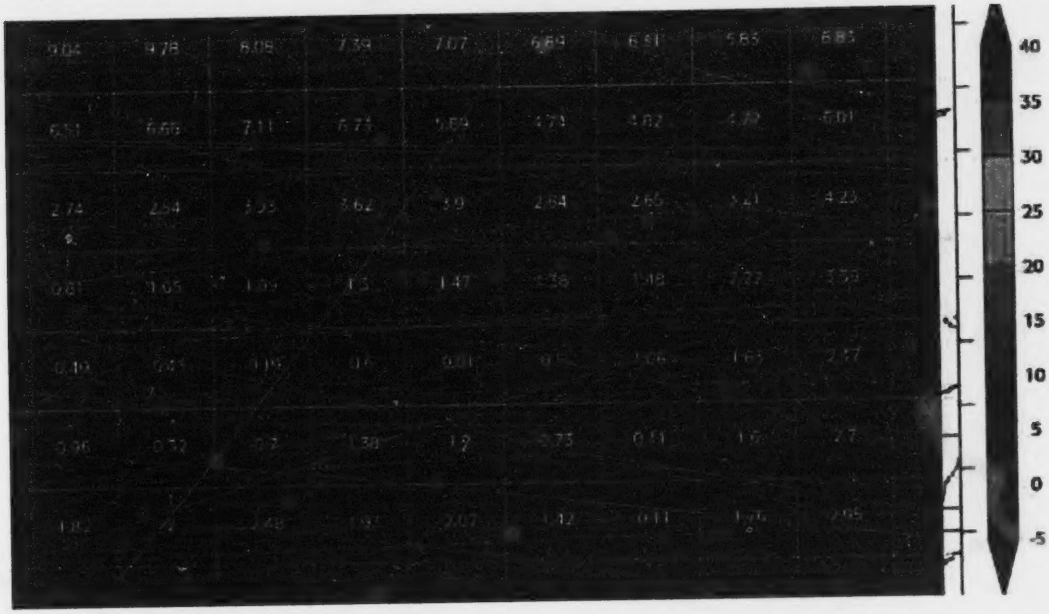


Figure 17. *Ensemble scenarios of projected 2050 precipitation change relative to the 1961 – 1990 mean under moderate greenhouse gas emissions. Images obtained from the Canadian Climate Change Scenarios Network website (http://www.cccsn.ca/ensemblescenarios/ensembles-e.html)*

Table 3: The ranges of the mid 21st century (2041-2070) temperature and precipitation increases relative to the average of 1961-1990 mean temperatures and precipitation based on the ensemble climate change scenarios for the Far North. When a range is given for a variable for a particular scenario, the range is from the southern to the northern portion of the Far North. "Low", "Medium" and "High" refer to the lowest, middle and highest range of CO_2 increase emission scenarios.

	Low	**Medium**	**High**	**CRCM High**
Variable/Scenario				
Temperature (°C)				
Annual	3	3.5	4	3-3.5
Winter	3-4.5	3-5.5	3.5-6	4-7
Spring	2	2.5	2.5-3	2-2.5
Summer	2-1.5	2.5-2	2.5	3-3.5
Autumn	2-2.5	2.5	2.5-3	4-3
Precipitation (%)				
Annual	5-10	5-10	5-10	10-25
Winter	15-25	15-30	15-35	30-60
Spring	10	10	5	15-25
Summer	0-10	0-10	0-10	5-15
Autumn	5-10	5-10	5-15	0-20

Projected percent change in average summer precipitation in the 2050s

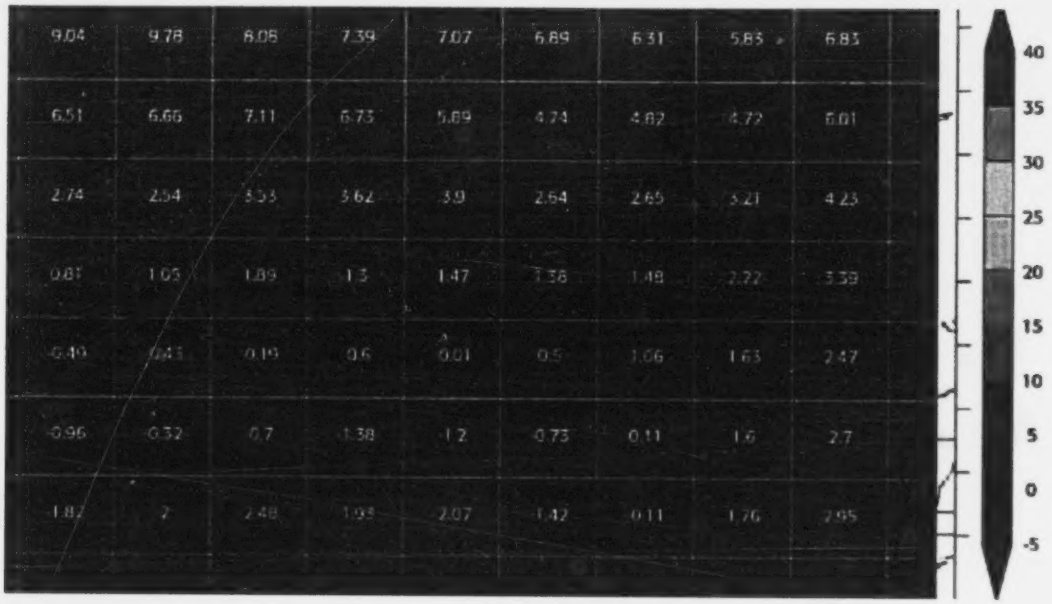


Figure 17. *Ensemble scenarios of projected 2050 precipitation change relative to the 1961 – 1990 mean under moderate greenhouse gas emissions. Images obtained from the Canadian Climate Change Scenarios Network website (http://www.cccsn.ca/ensemblescenarios/ensembles-e.html)*

Table 3: The ranges of the mid 21st century (2041-2070) temperature and precipitation increases relative to the average of 1961-1990 mean temperatures and precipitation based on the ensemble climate change scenarios for the Far North. When a range is given for a variable for a particular scenario, the range is from the southern to the northern portion of the Far North. “Low”, “Medium” and “High” refer to the lowest, middle and highest range of CO_2 increase emission scenarios.

	Low	**Medium**	**High**	**CRCM High**
Variable/Scenario				
Temperature (°C)				
Annual	3	3.5	4	3-3.5
Winter	3-4.5	3-5.5	3.5-6	4-7
Spring	2	2.5	2.5-3	2-2.5
Summer	2-1.5	2.5-2	2.5	3-3.5
Autumn	2-2.5	2.5	2.5-3	4-3
Precipitation (%)				
Annual	5-10	5-10	5-10	10-25
Winter	15-25	15-30	15-35	30-60
Spring	10	10	5	15-25
Summer	0-10	0-10	0-10	5-15
Autumn	5-10	5-10	5-15	0-20

Several distinct patterns emerge that are common to all sets of ensemble projections for the mid-point of the 21st century (see Table 3 and Figs. 16 and 17). Annual and seasonal mean temperatures increase between 2 and 6°C depending on season and location (Fig. 16). The largest temperature anomaly is for the winter (December, January, and February) in the most northern part of the Far North, along the Hudson Bay coast. The magnitude of the anomalies increases from south to north in winter and spring but the reverse pattern occurs in summer. This is because of the proximity of the Far North to Hudson Bay and James Bay. These two bays are the world's largest, cold, inland seas and they have a profound effect on the climate of the Far North. In the projections they significantly attenuate the summer anomalies; the greatest attenuation is at the coastline of the Hudson Bay Lowland. Precipitation in that region increases moderately in all seasons and all scenarios (Fig. 17). As with temperature, the largest positive anomalies occur in winter, presumably because of the additional atmospheric moisture that comes with warmer temperatures. However, while there is general agreement on the patterns for temperature change, there is divergence in the patterns of precipitation change among the models in the ensemble analysis. The patterns of the ensemble analysis are very close to those of the CGCM2 analysis discussed by Colombo et al.

The implications of these changes for Far North ecosystems are discussed in the next sections.

3.1.1 Projected Impacts of Climate Change on Far North Ecosystems

Climate change is projected to affect Far North ecosystems directly through physical changes, and indirectly through factors such as moisture and temperature that in turn influence ecosystem structure and function. However, even when species assemblages do not change significantly, system function may be altered in fundamental ways, for example through changes in the rate of photosynthesis and autotrophic respiration and thus net primary production. This, in turn, could have a profound effect on ecosystem carbon biogeochemistry. Chapter 4 discusses the relationship between biodiversity, ecosystem resilience, and the ability of ecosystems to withstand disturbance, whether through climate change or some other influence from altered land use and development.

It is likely that some of the most dramatic changes will occur in the most northern extent of the Far North, near the coasts of Hudson Bay and James Bay. A considerably shorter ice cover season in these inland seas will lead to warmer and longer duration summers, and warmer and shorter winters (Fig. 16). This, in turn, will lead to the loss of permafrost, changing the surface hydrology and local topography. The plants and animals of this region are well adapted to the extreme climate conditions, but as climate change progresses and ecosystem structures exhibit profound changes, these relationships will be challenged. As one example, there has been considerable discussion in the literature as to how changes in sea ice will influence the ecology of the polar bear[104].

Changes in the amount and seasonal distribution of precipitation will alter the winter versus summer regime of lakes, rivers, and streams, with potentially significant effects on a variety of species. While the total amount of moisture may not change, the proportion that falls as rain rather than snow is likely to increase. Greater winter precipitation combined with earlier spring melt could lead to larger spring stream flows and increased potential for flooding. On the other hand, if winter rains run off, lower spring flows could result, as surface storage in the snowpack is depleted. Warmer average temperatures will mean a longer summer. While the projections indicate no significant reduction in summer precipitation, the earlier melts and the increase in average air temperatures are likely to increase evapotranspiration rates, which will lead to reduced water availability, lower summer water levels in lakes and streams, drier wetlands, and greater soil moisture deficits in upland forests.

There are many potential synergistic effects of climate change that are difficult to predict but which are of sufficient concern that they should be given serious consideration. One important example is the interaction between climate change and the levels of mercury (Hg) contamination in fish. There is evidence from other systems that Hg concentrations in fish may be rising in recent years despite no evidence of increased atmospheric deposition[105]. Wetlands, particularly peatlands, store a considerable mass of principally-immobilized Hg because of its association with sulphide. With a lowering of peatland water tables, sulphide can be converted to sulphate, mobilizing Hg and other metals in association with dissolved organic carbon, with potentially significant impacts on downstream consumers. The combination of soil warming, permafrost thaw, and increased release of dissolved organic carbon to rivers and estuaries could therefore lead to higher Hg concentrations in prime food fish, including those that move from salt to fresh water.

The hydrology of peatlands is intimately linked to climate through direct precipitation input, or with the addition of indirect precipitation input, via lateral inflow. The excess water typical of peatland systems is created by inputs exceeding outputs. Changes in climate will therefore affect peatlands by altering water inputs and/or increasing outputs, particularly through increased losses by evapotranspiration. Climate change also has the potential to alter exchange of CO_2 and CH_4, and consequently carbon storage, in peatland systems. As discussed in Section 2.4, the radiative properties of the two gases are very different. Changes in CH_4 emissions are most important over the short term (< 100 years) but ultimately it is the exchange of CO_2 that determines the longer term role peatlands play in regulating climate.

Table 4 illustrates the four possible temperature-moisture combinations that may arise with climate change; each has a different set of consequences for the exchange of CO_2 and CH_4 with the atmosphere. However, as earlier discussion has demonstrated, future climate projections based on a range of emission scenarios limit the range of possibilities for the Far North to warmer conditions only. Precipitation outcomes are less certain, although most models indicate a range of possibilities, from a moderate increase in precipitation to a larger potential decrease. It is therefore highly unlikely that the peatlands will be wetter in the future, since temperature effects on water loss by evapotranspiration are likely to be greater than increases in precipitation; however, the degree of change in water storage is dependent on the topographic setting of the peatland and the presence or absence of permafrost.

Models of peatland carbon cycling coupled to climate models are only just beginning to become available[106]. Simulations of a bog and fen located at boreal latitudes similar to those of the Far North indicate warmer and drier conditions. They also show that fen peatlands are much more sensitive to climate change than are bogs. Simulations for the highest atmospheric CO_2 concentration scenarios (e.g., A2, A1FI) show that by the mid 21st century the uptake of CO_2 in bogs becomes marginally less (~ 25% reduction), while fens begin to become moderate sources of CO_2 to the atmosphere[107]. If these scenarios are run through the entire 21st century, the high concentration cases result in a globally significant release of CO_2 of ~ 25 to 35 Gt C, which is equivalent to between 10 and 20% of the total positive feedback for all other terrestrial ecosystems[108], even though peatlands represent only 3 to 5% of the land cover. If this value were scaled to the peatlands of the Far North, the range of potential biospheric feedback for CO_2 is 0 to 3 to 4 Gt C. For comparison, the upper range of this estimate is roughly equivalent to 50 to 75 years of the greenhouse gas emissions reported for Ontario in 2005 (205 Mt)[109].

Table 4. Possible changes in greenhouse gas exchanges with combinations of changes in temperature and moisture conditions in peatlands of the Far North. + indicates an increase and – indicates a decrease in the flux. 'up' indicates CO2 uptake, 'em' emissions, and 's' source.

Moisture/Temperate	**Warmer**	**Colder**
Wetter	CO_2 up +++ CH_4 em ++	CO_2 up + CH_4 em -
Drier	CO_2 up/s — CH_4 em —	CO_2 up - CH_4 em —

The magnitude of the CH_4 response has not yet been incorporated in peatland biogeochemical models but empirical observations from peatlands in regions of discontinuous permafrost indicate that permafrost thaw will lead to complete changes in the vegetation structure. That is, dry moss/shrub-dominated bogs become wetter sedge-dominated fens, and this in turn leads to a 10 to 15 fold increase in CH_4 emissions[110]. There are no similar studies for peatlands in regions of continuous permafrost but an increase in permafrost active layer depth would likely lead to drier peatlands, and therefore a reduction in CO_2 sequestration and CH_4 emissions. To be able to assess the potential feedbacks in the Far North, existing peatland hydrological, thermal and ecosystem-biogeochemical models need to be developed further to incorporate CH_4 cycling, vegetation dynamics and permafrost.

It has been shown that peatland systems can be characterized as complex adaptive systems (CAS)[111]. Negative feedbacks in peatlands result in a somewhat self-regulating interaction between hydrology and peatland growth (carbon accumulation), which have resulted in continual growth of peatlands over the Holocene despite considerable climate variability. However, it is not at all clear if these self-regulating mechanisms can be sustained at the pace of present-day climate change. If the rate of change exceeds a limit of rate adjustment, peatland dynamics will be difficult to predict using current tools, because the simple models currently used to predict response to climate change are not likely to be adequate. In areas where peatlands are extensive and permafrost is likely to occur, large and sudden changes in peatland structure and function could be expected, as has been observed in northern Sweden[112]. Fire could be another tipping point in peatland carbon dynamics. Current models need to be advanced to incorporate these possibilities. These concerns are very relevant to the Far North where much of the peatland in the Hudson Bay Lowland is associated with permafrost. Fire would be expected to be an issue for boreal peatlands in the western half of the Far North.

The impacts of future climate change on Far North forests are likely to be severe, but there is considerable uncertainty regarding specific impacts. Growth of boreal trees generally shows a positive trend with higher temperatures in the historical record[113] but, beyond some threshold, growth reductions are expected, and recent studies have documented temperature-related growth declines[114]. In Alaska, the optimal July-August mean temperature for white spruce was estimated at 11.3°C, a temperature that has been exceeded on average since the mid-1960s[115]. Climate change in the boreal forest is also predicted to impact tree growth and survival through processes other than increases in growing-season temperatures. Boreal forests may also be showing changes in growth due to increased length of growing season[116], and changes in freeze-thaw cycles[117]. Negative impacts on boreal forest include temperature-induced drought stress on boreal trees,[118] and (as noted previously) increasing fire frequencies[119]. Also likely are increased impacts of insect pests such as spruce budworm, jack pine budworm, and forest tent caterpillar[120]. Climate-envelope models have predicted large changes in future species composition of Far North forests[121]. Predicted declines in black spruce, which is very sensitive to increased growing-season temperature[122], are of particular concern.

In the Shield area, increased disturbance levels and dieback of some species because of climate change will alter vegetation composition[123], although here again specific outcomes are difficult to predict. A shift to grassland or to deciduous trees could result in a negative feedback through increased albedo[124], causing such water-limited systems to have lower carbon storage[125]. On the other hand, expansion of the boreal into tundra regions may cause an increase in vegetative carbon stocks[126]. Northward spread of the treeline would also result in a lower albedo, and a possible positive feedback to climate change[127]. In addition, soil carbon stores could be reduced during the shift from tundra and peatland to forest[128].

The potential for, and implications of, northward spread of boreal forests have received no attention yet in woodland-wetland landscapes such as the Hudson Bay Lowland. Indeed, there has been little formal research on climate change impacts on forests in the Far North, or in directly comparable regions elsewhere, so lessons must be drawn from systems farther south in Ontario and in other parts of Canada, Eurasia and Alaska. In terms of forest resources, the most critical gaps are assessments of forest productivity and impacts of land use options on forest structure, dynamics, and ecosystem functions. *Ontario's Crown Forest Sustainability Act* requires *"forest practices that, within the limits of silvicultural requirements, emulate natural disturbances and landscape patterns."* Neither the silvicultural requirements, natural-disturbance regimes nor the landscape patterns of the Far North are adequately documented to meet this test, with the exception of the shared ecoregions along its southern edge[129].

3.1.2 The Case of Fire, Carbon and Climate Change

The release of atmospheric carbon by wildfire averages 27 Tg carbon/yr for Canada[130]. This is about 20% of the carbon released from fossil fuel burning nationally. In a severe fire year, the amount of carbon released from wildfire can equal or surpass the amount of carbon emitted from burning fossil fuels. However, while the burning of fossil fuels is a one-way process that results in a net increase of carbon to the atmosphere, forest fires also lead to natural regeneration of new forests that sequester carbon. Fires play a major role in determining net carbon in the biome through direct losses due to combustion and indirect losses associated with the decomposition of the fire-killed vegetation. In the case of stand renewal, young successional stands can more rapidly sequester carbon than older forests. Current models predict that Ontario will experience a 25 - 100% increase in fire starts by 2090[131]. For Canada, projections are for a 75%-120% increase in area burned by 2090, with increases of up to 300% modelled for the Far North of Ontario[132]. The same researchers have predicted future levels of fire protection for Ontario, using an established level-of-protection analysis used in the Province. They assumed an increase in fire occurrence and an increased potential for fires to spread, and concluded that to maintain the current level of protection (i.e., maintain the same level of fires that escape initial attack), Ontario would have to double its fire-suppression resources.

Temperature is the most important variable in determining wildland fire, although moisture also plays a significant role. Warmer temperatures increase evapotranspiration, thereby lowering water-table position and decreasing fuel moisture levels. These impacts might be avoided if there are significant, off-setting increases in precipitation, however based on the ensemble analysis discussed above this is not likely. Warmer temperatures translate into more lightning activity, which generally leads to increased ignitions[133]. In addition, warmer temperatures will likely lead to a lengthening of the fire season[134].

The future fire regime for the Far North therefore includes more fires, more intense fires, an increased area burned, and longer fire seasons. There will be an increased area of peatland fuels available for burning due to the loss of permafrost and, perhaps, peatland drying (see previous section). There may also be more ignition sources from expanded industrial activity, increased human activity due to the development of new roads, and from an increase in lightning strikes. Suppression effectiveness is uncertain and will be costly to expand. The net result will be an increase in fire, leading to an increase in CO_2 emissions.

3.1.3 Communities: Adapting to Climate Change Impacts

Given the projections of climate change described above it is inevitable that there will be considerable impact on the communities of the Far North. Impacts will vary depending on the latitude and geographic location of the community. However, the consequences of shorter, warmer winters, possibly accompanied by increased snowfall, may well include disruption of travel on snowmobile routes and transportation on winter roads in many communities. These challenges may be exacerbated by increased spring runoff and flooding throughout the region, and have significant implications for infrastructure and resource development, including roads and infrastructure corridors and mining operations. It is therefore critical that such development should only proceed after the potential impacts of climate change have been taken into account in the planning process.

The national Centre for Indigenous Environmental Resources in Winnipeg has produced a strategic climate change adaptation framework that provides tools to assist First Nations. Additionally, a report prepared for the Assembly of First Nations, *Climate Change and First Nations: Recommendations for Action*, identifies some of the most critical and immediate responses. Ultimately, however, increased climate resilience in Far North communities must be sought through appropriate community based engagement involving the use of traditional aboriginal knowledge as well as climate change science. We note that the recent report of Ontario's *Expert Panel on Climate Change Adaptation* recommended that climate change risks for Far North communities should be assessed along with their adaptive capacity. Given the implications of climate change for First Nations transportation, food, and water supply, it is essential that community land use plans incorporate an assessment of climate change impacts and the community's ability to adapt to those impacts.

3.2 INTERNAL DRIVERS OF CHANGE

Whereas section 3.1 discussed climate change as an external driver of change beyond the control of Far North communities and development interests, this section describes activities taking place within the Far North that can be managed to minimize or eliminate the loss of biodiversity and/or ecological function.

As in Ontario in general (with the exception of manufacturing) retail, health care, education, transportation and construction dominate employment in the Far North. However, the population is smaller and hence far fewer people are employed than in other parts of the Province. Far North communities are connected by broadband internet access and by satellite radio and television, but they are physically separated more than other Ontario communities. Only one community is linked to surface transportation southward by an all-weather road, and only one other community is linked south by rail. Winter roads serve most communities and they bring in fuel for their diesel generators on these roads. Communities are also connected by air, and snowmobiles and all-terrain-vehicle travel are commonplace.

The following sections describe the principal human activities that have the potential to affect ecological integrity in the Far North, both singly and locally, and cumulatively over space and time. Cumulative impacts in particular require careful attention, as the human footprint in the Far North widens and deepens.

3.2.1 Settlements and Associated Infrastructure Support

The Far North has a very small population distributed among 34 communities; as a result, the density of people in this vast area is one of the lowest on Earth. The environmental footprint of settlement sites is currently very small relative to southern communities, especially because of the current lack of all-weather transportation infrastructure and the paucity of community based industries and manufacturing. However, for local land use planning it is important to note that even the current settlements do exert measurable and sometimes significant effects on local fish and wildlife populations, land resources such as adjacent forests and wetlands, and important impacts on local environmental quality, such as land and water contamination, that affect the health and lives of local people. As noted previously, drinking water supplies have been contaminated by poor septic facilities in the Far North; local air and noise pollution also arises from the use of diesel generators for electricity.

3.2.2 Energy Generation and Distribution

Many communities in the Far North rely on diesel generation for the production of electricity. Locally-based renewable energy projects offer the potential to reduce this reliance on external supplies and decrease associated pollution, including release of greenhouse gases. Renewable energy development can also create economic benefits for communities, in the form of employment, taxes, and economic agreements. However, these benefits must be balanced against the environmental consequences of energy development, especially large-scale hydro-electric projects.

Hydro-electric Development

The potential ecological impacts of hydro-electric development depend on the type of structure and its mode of operation. Reservoir or storage systems involve the construction of a dam, behind which water is stored, for later release through a turbine. By contrast, run-of-the-river installations use much lower diversion structures, and sometimes no dam at all, to divert the natural river flow through the turbine via a penstock. Run-of-the-river facilities result in much less terrestrial inundation than storage facilities and associated reservoirs, and are generally preferred over storage facilities for maintenance of fish migration. Regardless of the type of installation, the scale of the project must also be taken into consideration in a discussion on ecological consequences of hydro-electric development.

OMNR's waterpower potential database identifies 38 sites in the Far North as having potential generating capacities of greater than 25 MW. Sixteen of these are sites with potential greater than 100MW, on the Severn, Winisk, Attawapiskat, Albany and Moose Rivers. The total theoretical potential for these rivers has been estimated at 4,600 MW. In addition, there is considerable potential for small-scale local production of hydro-electric power for communities in the north, thus reducing or eliminating the need for reliance on diesel generation. Even quite small rivers can generate considerable electrical power by simply shifting some of the flow through turbines in a run-of-the-river system. While efforts have been made in recent years to improve the precision of the estimates in OMNR's database, current estimates are based on data collected through field surveys conducted in the early part of the 20th Century. It is highly likely that climate change will change these estimates.

Hydro-electric development in the basins of the Albany, Attawapiskat, Winisk and Severn Rivers is controlled by the Northern Rivers Commitment, which sets out that there will be no development greater than 25 MW in those basins. Development less than 25MW can proceed if it is proposed by the local Aboriginal community or communities and/or their partner(s)[135]. This commitment was made in response to community concerns about the potential for extensive flooding associated with hydro power development. It is included in the OMNR Waterpower Site Release and Development Review policy, approved in 2004[136].

The impacts of hydro-electric development include the direct loss of terrestrial habitats through dam construction and reservoir impoundment, altered estuarine dynamics[137], altered streamflow regimes, and associated shoreline erosion and scouring of river channels[138]. The amount of erosion and soil loss varies widely with soil type, the relative area flooded, and the range of fluctuations in water levels[139], but can result in high suspended sediment load and turbidity[140] and significant alteration of spawning habitat for fish such as brook trout[141]. In the discontinuous permafrost terrain of northern Manitoba, flooding of South Indian Lake and the Rat and Burntwood rivers was shown to cause extensive shoreline erosion and thermokarst slumping[142]. Extensive flooding of land can cause the release of mercury, carbon dioxide and methane, and can shift systems from being carbon sinks to carbon sources[143]. In the case of shorter turnover-time carbon pools such as living biomass, this loss of carbon uptake amounts to several decades, but in the case of the longer-term pools such as soil carbon and peatlands, the slow persistent loss of storage could amount to a significant net loss of carbon service.

Reservoir construction results in the flooding of organic matter, which releases dissolved organic carbon. Inorganic mercury combines with carbon in the presence of microbial activity and is converted to the highly bioavailable organic form, methyl mercury[144]. Predatory fish are particularly prone to methylmercury accumulation in their tissues[145], with the highest trophic levels exhibiting the highest body burdens of methyl mercury. It can take many years for an impoundment to return to the physical and chemical conditions typical of those in natural lakes[146].

Dams can also create barriers to fish migrating from salt water up rivers to spawn, and can affect migration patterns between fish populations[147], and cause changes in species composition by differential mortality or injury to certain species or sizes of fish passing through turbines. Habitat fragmentation by dams is considered responsible for declines in sturgeon populations by blocking movements and reducing habitat diversity[148].

Wind-Energy Development

Much of the Far North has moderate to very high potential for wind power generation in terms of wind velocity patterns. The coast and off-shore region of James Bay and Hudson Bay have some of the highest potential, but the lack of access, transmission infrastructure and nearby markets limits the feasibility of wind power development in these coastal areas. There is also a band of good wind potential that runs inland from the very northwest corner of the Far North across the Province, along the intersection of the southern extent of the Lowland and the northern extent of the Canadian Shield. Unpublished data provided by the Ontario Power Authority have identified 32 potential sites with an estimated total wind generation potential of 3,900 MW.

While the lack of major transmission infrastructure currently limits the potential for development of wind power to feed southern markets, wind energy is a very promising option for local development, where transmission infrastructure would be limited to the local area. This approach would allow communities to reduce or eliminate their dependence on diesel generators, especially if coupled with small-scale hydro-electric power (the intermittency of wind power makes it an unreliable source to supply local base load requirements).

The large-scale and long-term effects of wind-energy facilities on organisms are difficult to predict, but species that have life history characteristics such as low birth rate, long life span, naturally low mortality rates, and small geographic ranges are likely to be most at risk[149]. Wind-energy development may have a disproportionate impact on certain ecosystems, especially when it is focused on specific topographic characteristics that are key habitat features for certain species[150].

Some of the highest wind power potential exists in coastal areas, which are also important staging areas for waterfowl and shorebirds. Wind-energy facilities have been demonstrated to kill birds and bats through collision with wind turbines[151], and can also result in loss of habitat for some species. Species may display behavioural changes or avoidance of the site due to the noise, vibration, or blade motion associated with the installation. European studies have shown reductions in bird numbers of up to 95% at distances of 250-500 m from wind turbines[152].

3.2.3 Transportation and Transmission Corridors: Roads and Other Linear Features

The current lack of an all-weather road and rail network in Far North of Ontario is widely regarded as an impediment to its future economic growth and access to its abundant natural resources, including mines, energy development, and industrial forestry. Similarly, new high-voltage transmission lines will be necessary to deliver electricity to replace diesel as a power source in Far North communities, and to feed the grid in southern Ontario. The current lack of all-weather road access in the Far North also exacerbates the disadvantages isolation brings to First Nations communities there. Road networks link communities to services in the south, promising better health care, education, and cheaper goods, albeit often with secondary social costs. Hence, new roads and other linear features will figure prominently in the future efforts aimed at "connecting and strengthening Northern communities"[153].

In most parts of the world, road density is correlated with human settlement density and is a strong indicator of the human footprint[154]. In the Canadian North, however, resource extraction activities have resulted in relatively dense road networks even in areas of low population density. For example, in large portions of northern Ontario, forest access roads blanket the region with few areas remaining that are more than 10 km from roads[155]. "Wilderness class" parks, such as Wabakimi and Woodland Caribou Provincial Parks, provide the only legal mechanism in the region for maintaining a roadless condition. Elsewhere, road networks and other linear features in Ontario are usually planned on the basis of economic need and to facilitate access to resources[156], and in a piecemeal project-by-project manner[157]. Environmental considerations seldom factor in the initial decision to build the corridor itself, but instead tend to be concentrated on mitigating its worst impacts. Such deliberation usually occurs late in the planning process following significant site investments in engineering design, which reduces the flexibility to adjust course to avoid anticipated impacts[158].

Impacts to both terrestrial and aquatic biodiversity from roads and other linear features – by themselves and in concert with development – have been well-documented. Studies of this nature have been conducted on a wide range of taxa, and an overall strong body of evidence has accumulated for the negative effects of roads on fish and wildlife populations[159]. Road impacts fall into several broad categories that are not mutually exclusive[160]:

- Imposing a barrier. Many animals behaviorally avoid roads due to habitat effects, traffic volume and speed, emissions and disturbance (e.g., from noise and lights). Roads thereby serve to fragment habitat of such organisms, constituting barriers to their migration and dispersal and/or causing stress with ultimate impacts to reproductive success. Roads typically cross thousands of streams requiring the construction of cylindrical culverts that can fragment aquatic habitats. Despite the best efforts under the Department of Fisheries and Oceans' regulations, it is impossible to avoid negative consequences to fish populations and deterioration of stream habitats that are critical for spawning and movement.

- Alteration of physical and chemical environment. Roads bring with them myriad changes to the physical environment that affect the corridor itself and adjacent habitats at various distances. These include but are not limited to changes in soil properties, surface water flow, sedimentation, run-off patterns, pollutants, noise, light, and erosion. Maintenance and continued use of roads contribute chemicals to the environment such as heavy metals, salts, nutrients, ozone, and organic pollutants.

- Providing access. Linear features of all varieties can ease movement through otherwise inhospitable terrain for invasive species, human hunters and anglers, and predators. These often incur shifts in the dynamics of interspecies interactions, with population declines of affected organisms a typical result.

- Direct mortality. Some wildlife populations are particularly vulnerable to high mortality rates through collisions with vehicles or during road construction. These include slow-moving organisms, those attracted to roads (e.g., for thermoregulation or roadside forage), and species with large movement ranges that have a high probability of encounter with roads during their daily and/or seasonal movements.

- Inviting cumulative effects. The effects of roads are incremental and cascading. Although a particular corridor may be built to serve a single purpose or development project, the prevailing pattern is for this to facilitate additional uses for different purposes, more road networks, and power transmission lines.

The Far North currently has only one permanent gravel road, extending northward from the end of Highway 599 at Pickle Lake to the northern shore of Windigo Lake (for access to the Musselwhite gold mine), and one railroad to Moosonee. Otherwise, a network of winter roads connects the 34 remote northern communities to the southern half of the Province. These roads must be built anew each year (often although not always in the same corridor), with the Province having invested $18 million in construction and maintenance costs on the network since 2004-05[161]. Winter roads are very vulnerable to warm weather, as was very evident in the winter of 2010. (A major power corridor has been constructed from Otter Rapids on the Moose River through the James Bay communities to the Victor Mine, but no permanent road has yet been built to service it.)

While much has been stated regarding the future need for transportation and transmission corridor development in the Far North, several major projects have actually reached the feasibility or engineering stage at this time, including: (1) a high-voltage transmission line, 430 kilometres in length, from the Nipigon area to the Pickle Lake area on a new 40-metre wide transmission corridor ("Hydro-One Northwest Transmission Expansion Project"), built explicitly to access hydro and wind resources in the Far North; (2) a new 350-kilometre railroad link to the Ring of Fire chromite-nickel-copper-gold deposits near McFauld's Lake; and (3) a year-round road to connect four First Nation communities and the Town of Moosonee on the west shore of James Bay to Highway 11. While none has received official approval, planning for these corridor projects is now well advanced outside community based planning processes and prior to the passage of Bill 191.

Linear features that are most likely to be developed in the Far North include winter roads, all-weather gravel roads, railways, and transmission lines. It is highly unlikely that roads in the Far North will be paved or that in most cases traffic on them will be heavy. Nevertheless, significant impacts to sensitive northern environments should be expected, particularly if the build-out of road networks is not carefully controlled at a regional scale and cumulative effects are not carefully (re)assessed with each individual project. Roads will enhance access to pristine lakes and waterways, thereby heightening the risk of overexploitation particularly through winter ice fishing[162] and the introduction of invasive species, including baitfish and other live bait[163]. Eskers constitute the most suitable substrate for road construction in environments of the Far North, but these are also relatively rare glaciofluvial features in lowland boreal forests. Eskers contribute substantially to regional biodiversity, for instance as travel routes for caribou, and as den sites for wolves, wolverines and other carnivores in a landscape that is dominated by exposed bedrock and permafrost[164].

The Province currently has few mechanisms to control the development and proliferation of roads serving mines, forestry operations, and similar activities. Ontario has a history of constructing permanent roads to encourage further development initiatives following the discovery of significant mineral deposits, e.g., permanent roads to Red Lake and Pickle Lake[165]. Moreover, even when the original intention is for logging roads to be temporary in nature, they are often kept open following the completion of forestry operations to accommodate the wishes of recreational user groups[166]. The new Green Energy and Economy Act has explicitly removed transmission as a dominant constraint to the development of new energy, with a particular eye towards the Far North.

Because the ecological effects of roads and other linear features tend to accrue in a nonlinear manner, roads and other corridors require careful planning at the outset to avoid or ameliorate ill effects from their building, maintenance, repair, and use by regional traffic. The full burden of minimizing environmental impacts cannot be left to post-construction mitigation efforts, most of which have a poor track record of effectiveness. Most evidence suggests that road density is a more important driver of impacts than road design[167], and should therefore be the focus of coordinated planning. Ecological thresholds are likely to depend on the overall amount of favourable habitat, the spatial design and density of the road network, and the extent of road effects[168]. As such, long-term persistence of the Far North biota and ecological integrity will certainly require the strategic setting aside of significant roadless areas.

3.2.4 Exploration and Development of Geological Resources

Exploration for Oil and Natural Gas

Exploratory drilling for oil in the sedimentary strata of the Lowlands, especially in the south near Moosonee in the Moose River Basin and more recently in the centre of Hudson Bay, began in the 1960s. No hydrocarbon discoveries with commercial potential have been made although potential shale source rocks have been identified[169] and hydrocarbon seeps are known in similar strata in the Arctic Islands[170]. Geological evidence suggests that the potential for conventional oil and gas is probably limited to the most deeply buried sediments near the centre of Hudson Bay – the Hudson Sedimentary Basin[171] (Fig. 6). A collaborative project involving the Federal government through Natural Resources Canada, and the governments of Nunavut, Manitoba and Ontario is currently examining that possibility[172].

Possible local sources of natural gas have been investigated along the south eastern limit of the Far North, where so-called "forest rings" appear to be related to biogenic gas seeps[173]. While there is community interest in these structures as a local source of energy, they are poorly understood and their potential is untested.

Metalliferous Deposits and Diamonds

Staking Activity

On March 12, 2007 there were 35,386[174] unpatented mining claim units (400m x 400m) in the Far North. Three years later the number had almost tripled to 90,579[174] with almost all of the increase being in the "Ring of Fire" region (Fig. 18). Claims in the Far North in March 2010, amounted to about 29% of those in the Province and 3.1% of the Far North land base[175]. Most claims outside the Far North are concentrated in the neighbourhood of existing mining camps in Northern Ontario, such as Timmins, Kirkland Lake, and Red Lake, where the regional geology is comparable to the Shield of the Far North.

In December, 2009, the President of the Ontario Mining Association reported that at least 50 agreements had been negotiated among mineral producers, mineral exploration companies and First Nations communities[176].

Landscape Scale Distribution Patterns

Landscape scale patterns for the distribution of metalliferous deposits and diamonds in the Far North are beginning to emerge. Greater knowledge of the rock types, interpretation of regional fault patterns, and

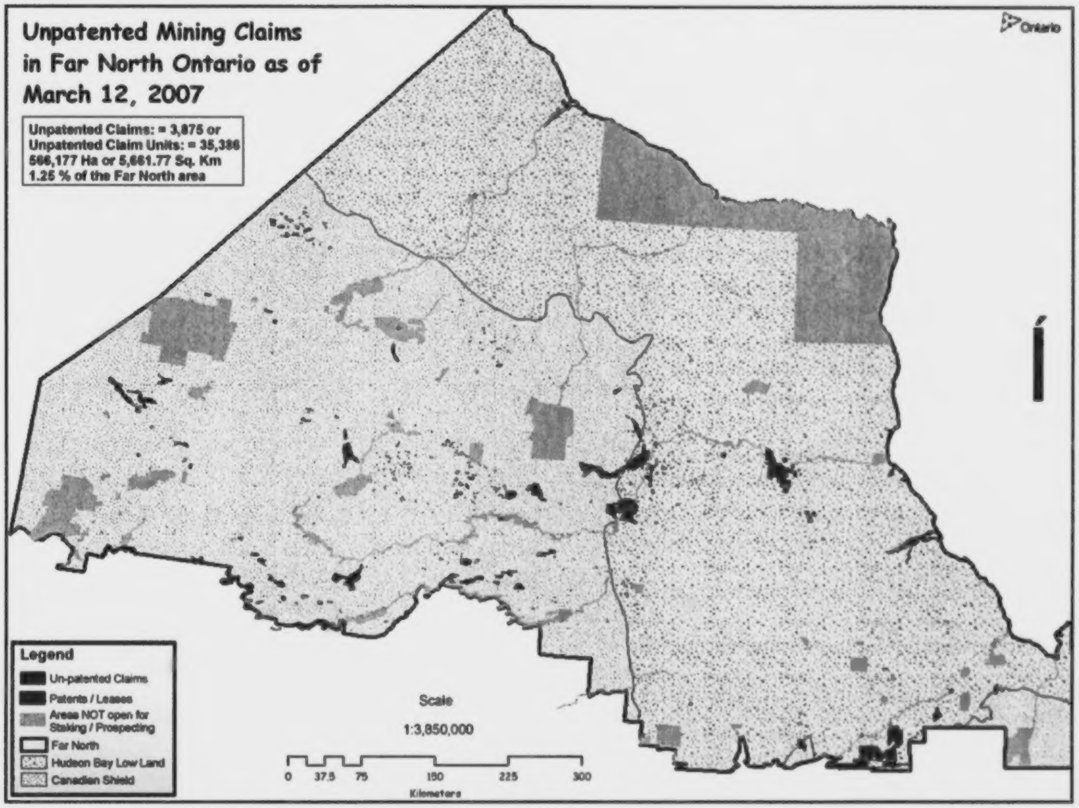
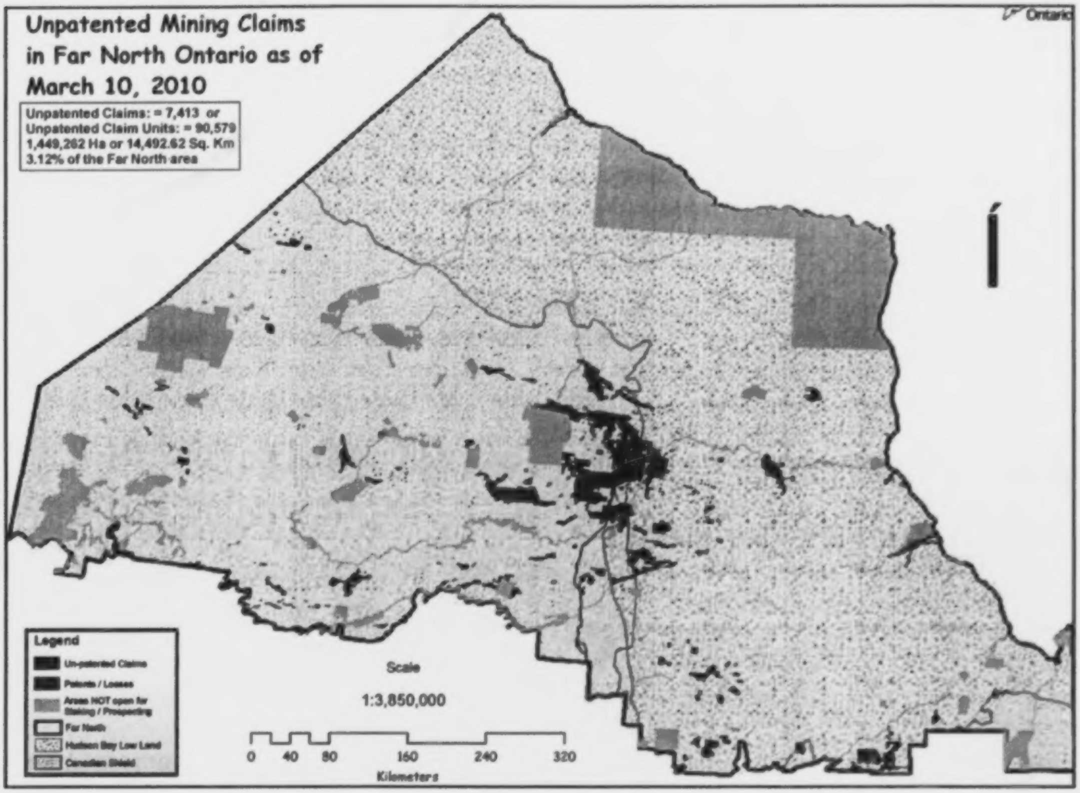

Unpatented Mining Claims in Far North Ontario as of March 12, 2007
Unpatented Claims: = 3,875 or
Unpatented Claim Units: = 35,386
566,177 Ha or 5,661.77 Sq. Km
1.25 % of the Far North area
Ontario
Legend
Un-patented Claims
Patents / Leases
Areas NOT open for Staking / Prospecting
Far North
Hudson Bay Low Land
Canadian Shield
Scale
1:3,850,000
0
37.5
75
150
225
300
Kilometers

Figure 18. *Location of mining claims in the Far North on a) March 12, 2007 and b) March 10, 2010 . The prominent concentration of claims near the centre of the Far North marks the "Ring of Fire."*
Source:Provincial Recording Office, OMNDMF, 2010.


Unpatented Mining Claims in Far North Ontario as of March 10, 2010
Unpatented Claims: = 7,413 or
Unpatented Claim Units: = 90,579
1,449,262 Ha or 14,492.62 Sq. Km
3.12% of the Far North area
Ontario
Legend
Un-patented Claims
Patents / Leases
Areas NOT open for Staking / Prospecting
Far North
Hudson Bay Low Land
Canadian Shield
Scale
1:3,850,000
0
40
80
160
240
320
Kilometers

identification of important geological boundaries are leading to broad scale geological frameworks for the potential distribution of different types of mineral concentrations. These emerging patterns can be seen in the Ontario Geological Survey's "Provincial Scale Exploration Opportunity" maps (http://www.mndm.gov.on.ca/mines/ogs/resgeol/rfe/default_e.asp, accessed March 4, 2010). The patterns shown in the figures used in this report are modified and updated versions of those OGS maps.

Two groups of deposits can be distinguished by the patterns of their occurrence in either i) linear corridors and clusters or ii) patchy remnants of volcanic rocks (greenstone belts):

1. **Linear geological corridors (Figs. 19, 20, 21)**

   Linear geological corridors occur along parallel "rift valley" style faults; zones where faults and shearing have taken place; and long fractured boundaries between large scale pieces of crust. In the Far North it appears that they often control the location of:

   1. Diamonds
   2. Rare earth elements in carbonate-rich igneous rocks (carbonatites)
   3. Nickel, copper and platinum group elements (Big Trout Lake type)
   4. Gold
   5. Rare earth elements in granitic igneous rocks (pegmatites)

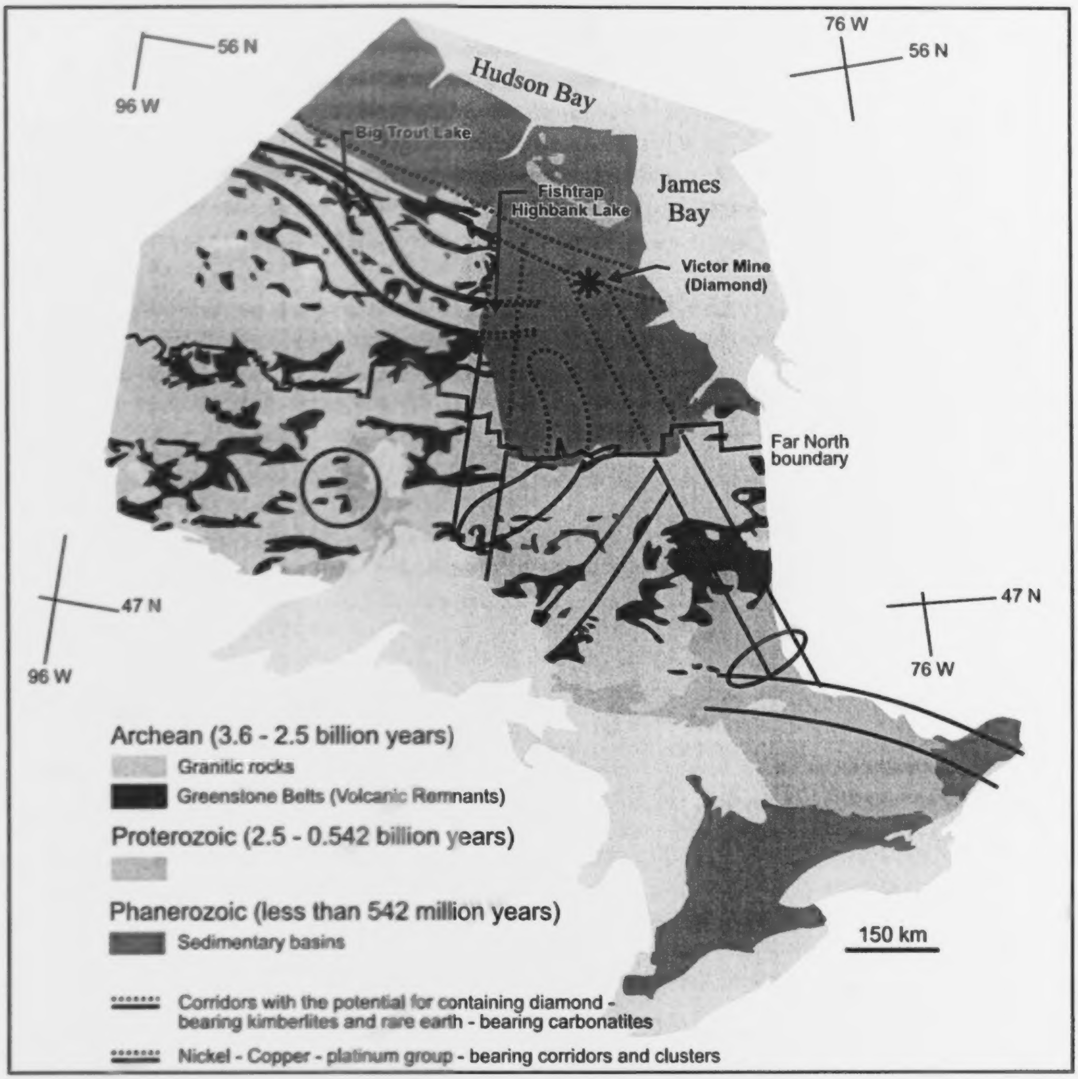

76 W
56 N
96 W
56 N
Hudson Bay
Big Trout Lake
Fishtrap
Highbank Lake
James Bay
Victor Mine (Diamond)
Far North boundary
47 N
96 W
47 N
76 W
Archean (3.6 - 2.5 billion years)
Granitic rocks
Greenstone Belts (Volcanic Remnants)
Proterozoic (2.5 - 0.542 billion years)
Phanerozoic (less than 542 million years)
Sedimentary basins
150 km
Corridors with the potential for containing diamond - bearing kimberlites and rare earth - bearing carbonatites
Nickel - Copper - platinum group - bearing corridors and clusters

Figure 19. *Corridors with the potential for hosting: i) diamond-bearing kimberlite pipes; ii) carbonatite intrusions carrying rare earth elements; iii) igneous rocks with nickel-copper and platinum group metals. (G. M. Stott, 2010, modified from http://www.mndm.gov.on.ca/mines/ogs/resgeol/rfe/default_e.asp accessed March 8, 2010)*

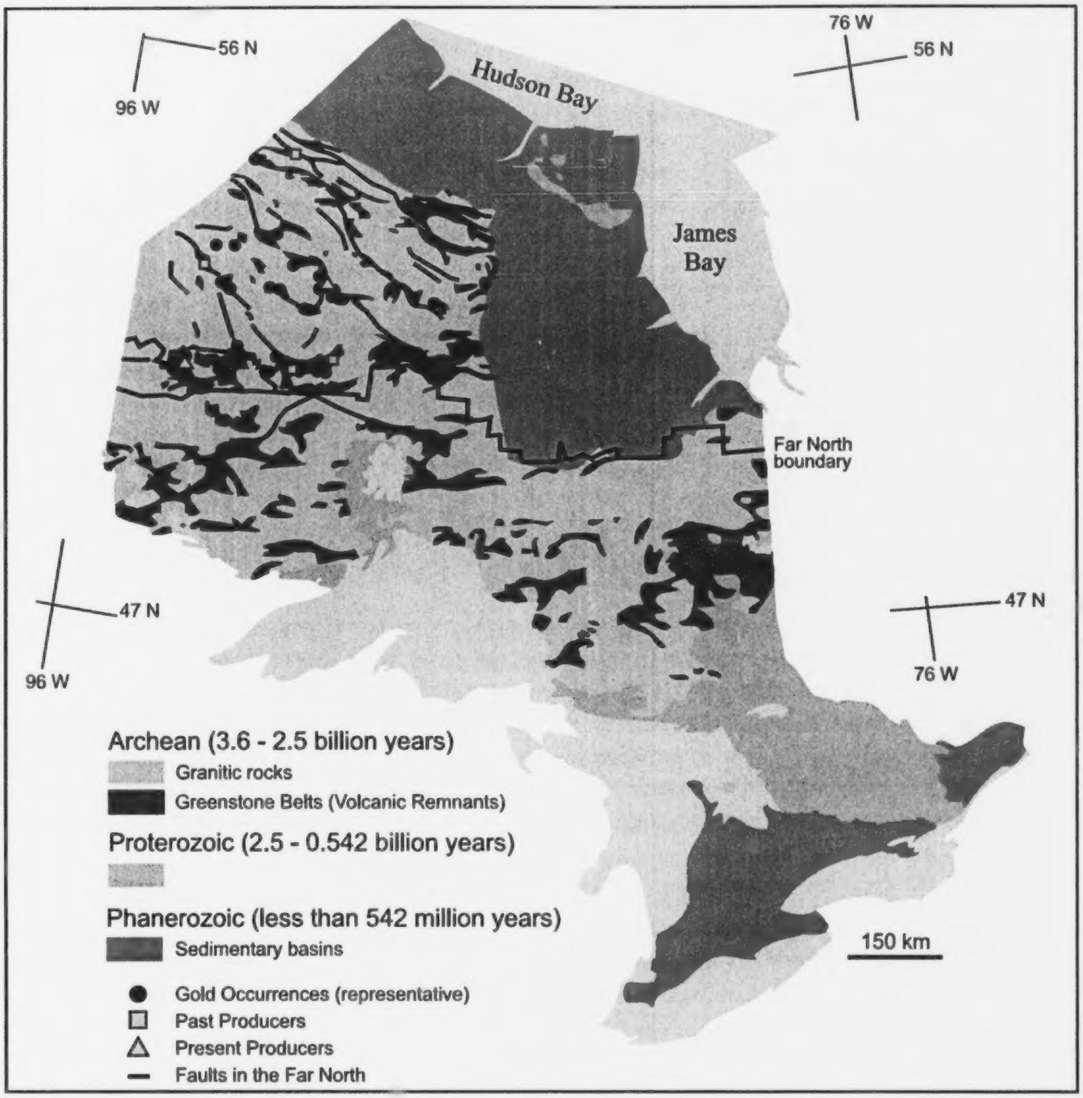

56 N
96 W
Hudson Bay
76 W
56 N
James Bay
Far North boundary
47 N
96 W
47 N
76 W
Archean (3.6 - 2.5 billion years)
Granitic rocks
Greenstone Belts (Volcanic Remnants)
Proterozoic (2.5 - 0.542 billion years)
Phanerozoic (less than 542 million years)
Sedimentary basins
150 km
Gold Occurrences (representative)
Past Producers
Present Producers
Faults in the Far North

Figure 20. *Corridors potentially hosting gold occurrences along fault zones close to or intersecting patchy remnants of volcanic rocks (greenstone belts). Source: G. M. Stott modified from http://www.mndm.gov.on.ca/mines/ogs/resgeol/rfe/default_e.asp accessed March 8, 2010.*

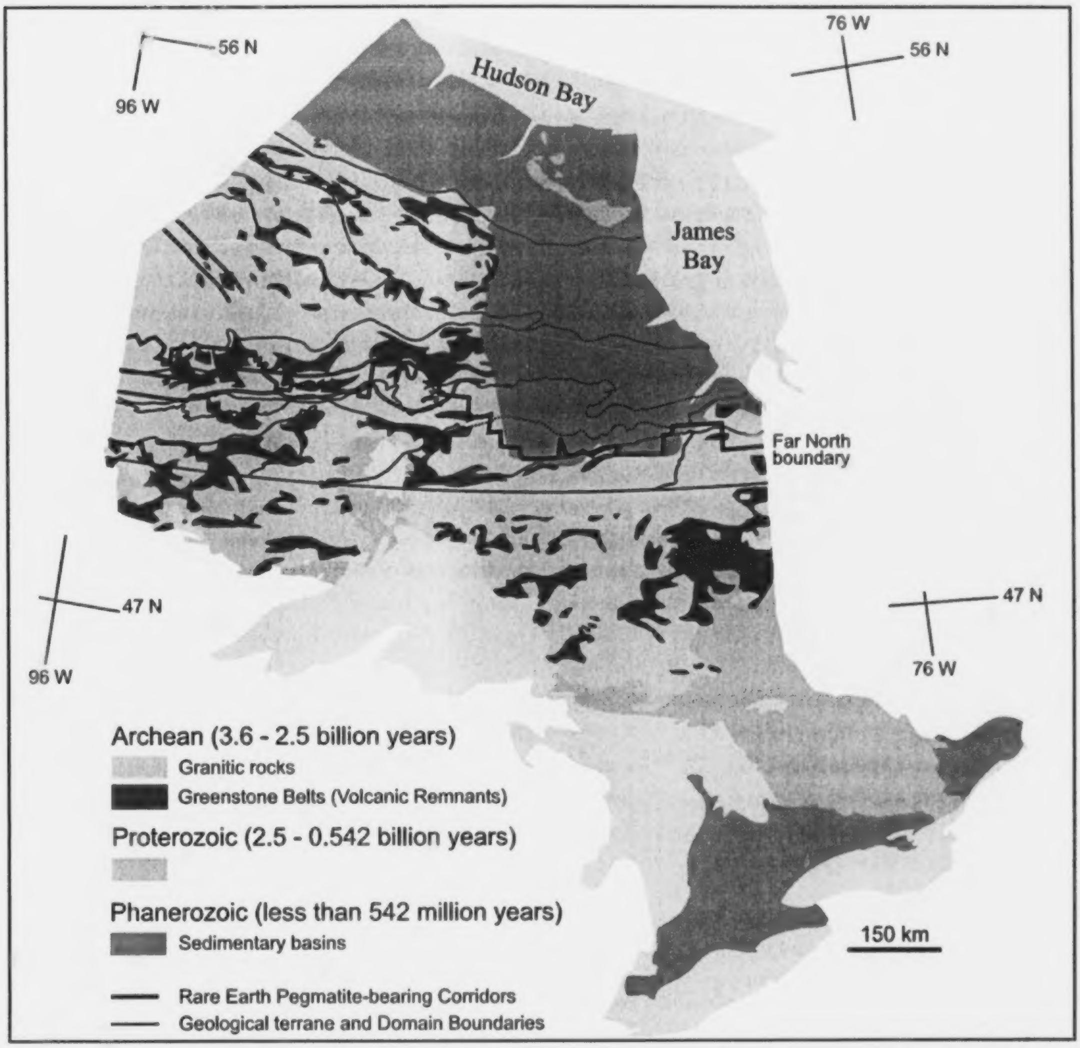

56 N
96 W
76 W
56 N
Hudson Bay
James Bay
Far North boundary
47 N
96 W
47 N
76 W
150 km
Archean (3.6 - 2.5 billion years)
Granitic rocks
Greenstone Belts (Volcanic Remnants)
Proterozoic (2.5 - 0.542 billion years)
Phanerozoic (less than 542 million years)
Sedimentary basins
Rare Earth Pegmatite-bearing Corridors
Geological terrane and Domain Boundaries

Figure 21. *Corridors associated with major faults hosting coarse, pegmatite granitic rocks containing rare earth elements, such as lithium, tantalum, cesium and rubidium. Source: G. M. Stott modified from http://www.mndm.gov.on.ca/mines/ogs/resgeol/rfe/default_e.asp accessed March 8, 2010.*

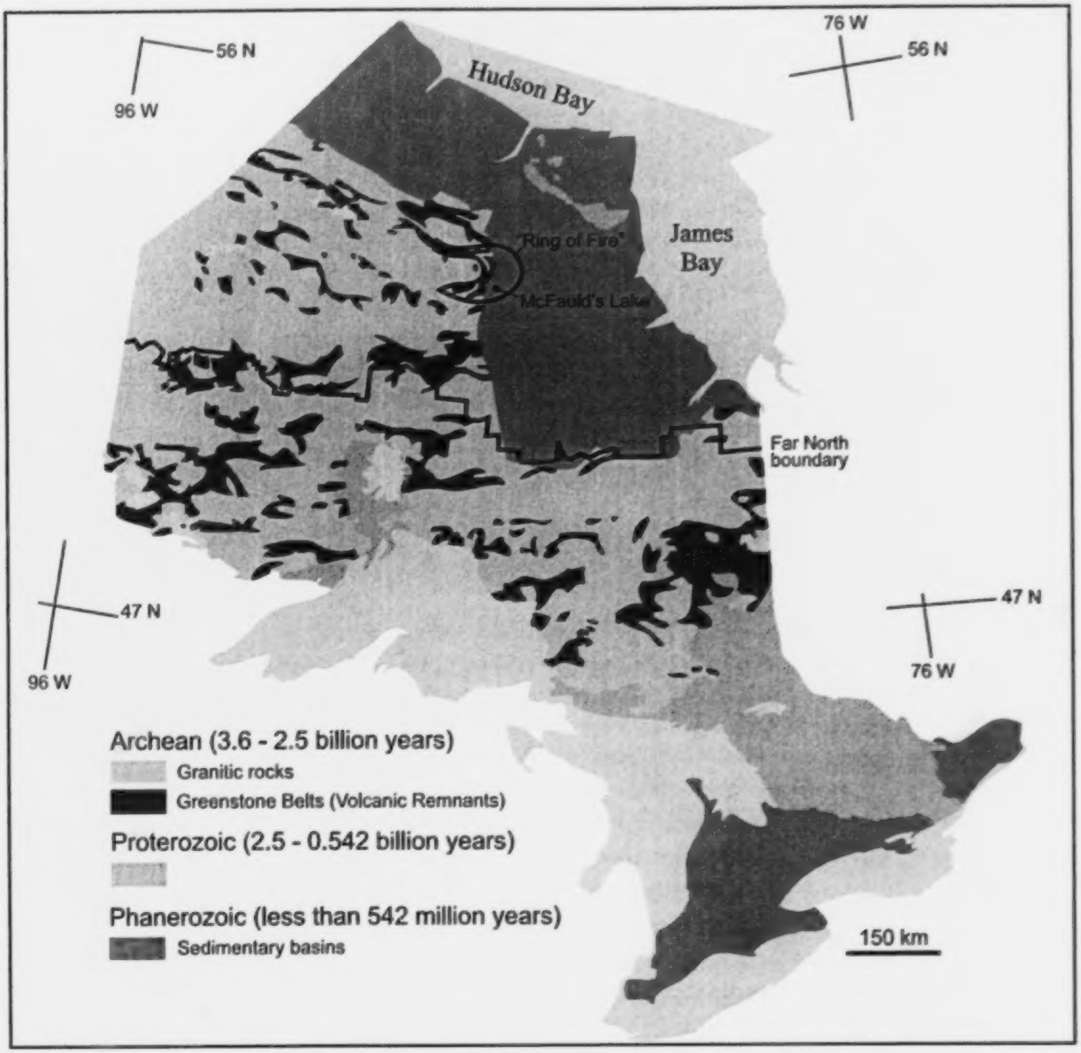

56 N
96 W
Hudson Bay
76 W
56 N
"Ring of Fire"
James Bay
McFauld's Lake
Far North boundary
47 N
96 W
47 N
76 W
Archean (3.6 - 2.5 billion years)
Granitic rocks
Greenstone Belts (Volcanic Remnants)
Proterozoic (2.5 - 0.542 billion years)
Phanerozoic (less than 542 million years)
Sedimentary basins
150 km

Figure 22. *Remnants of Precambrian volcanic "greenstone" belts that have the potential to host nickel, copper and platinum group metals; chromite and vanadium; and copper, zinc and gold deposits. Source: G. M. Stott modified from* http://www.mndm.gov.on.ca/mines/ogs/resgeol/rfe/default_e.asp *accessed March 8, 2010.*

2. Patchy volcanic remnants (Fig. 22)

The rocks of the Shield include the deep roots of volcanoes that erupted well over 2 billion years ago. Volcanic processes at such depths and at high temperature resulted in exceptional concentrations of metals and other elements now mined and used for industrial purposes. Remnant, landscape scale patches of these volcanoes are known as "greenstone belts" because of their colour. In the Far North they are known to host nickel and copper with platinum group elements (McFauld's Lake type); chromium and vanadium; as well as copper, zinc (base metals) and gold.

Diamonds

Diamonds are most commonly found in distinctive volcanic rocks known as kimberlites driven explosively to the surface from depths of up to 200km where diamonds are formed. Kimberlite "pipes" are typically located in small clusters no more than a few tens of kilometres apart in corridors marking old, deeply penetrating faults in thick cool crust in the interior of continents. Four such structural corridors have been identified in Ontario, all extending through the Far North (Fig. 22). So far diamond-bearing kimberlites have been found in two of the corridors. The first running north from Lake Superior and including the Kyle pipes north east of McFauld's Lake and the second through Temiskaming to the Victor Mine[177]. Only a small percentage of kimberlite pipes host commercially valuable diamonds.

Exploration for diamonds in the James Bay Lowlands began in 1960 through searches in glacial sand and gravel for indicator minerals carried by ice from kimberlite outcrops[178]. There are 19 kimberlite pipes in a cluster close to the Victor Mine, 16 of which have proven to contain diamonds[179]. Production at the Victor Mine began in July 2008, after a harmonized Federal and Provincial Environmental Assessment process and following ratification of several Impact and Benefit Agreements between De Beers Canada and neighbouring First Nations.

The open pit of the mine has been excavated in two overlapping pipes 90 km west of Attawapiskat. Production began in 2008 and is expected to last for 12 years[180]. About 2.5 M tonnes of diamond-bearing kimberlite will be processed annually over the mine's life of about 12 years, generating waste rock and tailings for disposal in the region. The mine produces high-quality diamonds, at about 25 carats/100t. Annual production is forecast at 600,000 carats[181].

Continuous pumping of water out of the Victor Mine pit[182] dewaters one or more small tributaries, and a large area of wetlands and peatlands around the mine site. The permit allows pumping of up to 150 m^3 per day for 5 years. It has been estimated that pumping will produce a cone of depression in the water table amounting to a diameter of 10 km or 75 km^2. Dewatering, drying and subsequent wetting of the peat has the potential to mobilize mercury historically deposited from the atmosphere and stored in the peat. A mercury monitoring program has therefore been set up to quantify any mercury released from the site[183]. Pumped water discharges into the Attawapiskat River.

In addition to the mine there are a number of support structures, including a processing plant, workshops, a warehouse, fuel storage, and an all-weather airstrip. The site is supported by a winter road from Moosonee and by air from Timmins. Power is supplied by a transmission line from Attawapiskat.

The Environmental Assessment process for the Victor Mine considered disruption of caribou, dewatering of the surrounding wetlands and peatlands, changes in the flow regime of the Attawapiskat River, and potential mobilization of mercury into downstream waters[184].

The longer-term production potential of the remaining kimberlite pipes in the area of Victor Mine remains speculative, but exploration of these pipes is ongoing and further mining with associated socio-economic opportunities for local Aboriginal communities is possible.

Rare Earth Elements in Potential Diamond Corridors

Rare Earth Elements ("REE" such as lithium, tantalum, rubidium, cesium, beryllium and gallium) have been found in unusual igneous rocks known as carbonatites that frequently (but not exclusively) occur in the same corridors as potentially diamond bearing kimberlite pipes (Fig. 19).

Nickel, Copper and Platinum in Potential Diamond Corridors

The corridor that includes Big Trout Lake and Highbank Lake has the potential to host kimberlite diamond pipes as well as being already known for igneous rocks in which nickel, copper and platinum have been found[185] (Fig. 19).

Gold

Gold is currently mined at the Musselwhite Mine in the Far North. Past production has occurred on the Sachigo River and the Berens River near the Manitoba border, and at the Golden Patricia Mine near Pickle Lake. New deposits have been reported near Pickle Lake, as well as in the McFauld's Lake ("Ring of Fire") area.

The occurrence of gold is frequently associated with linear fault zones in or adjacent to areas of patchy remnants of volcanic rocks known as greenstone belts (Fig. 20)[186]. Gold occurrences are much less amenable to detection through airborne geophysical methods than many other metallic deposits and require extensive on-the-ground prospecting.

Rare Earth Elements in Granitic Igneous Rocks (Pegmatites)

Rare earth elements are also found in coarse granitic igneous rocks (pegmatites) currently only recognized in the western part of the Far North. They occur in a corridor near North Spirit Lake and in another further south. These corridors are defined by long faults between very large scale pieces of crust (Fig. 21)[187].

Patchy Volcanic Rocks in the Precambrian Shield

Remnants of the roots of Precambrian volcanic belts, uncovered by more than 10km of erosion since they were formed as long as 3 billion years ago, are well known elsewhere in northern Ontario as hosts to a wide variety of metallic minerals. The various deposits discovered at McFauld's Lake are an example of these "greenstone belt" occurrences (Fig. 22). Exploration and geological mapping have yet to clearly identify the characteristics of the different volcanic remnants in the Far North, and the potential for discovery in greenstone belts is open throughout the region.

McFauld's Lake "Ring of Fire" Deposits

It was while drilling rocks that had been identified by airborne geophysics as a potential kimberlite target that De Beers and Spider Resources discovered copper-zinc sulphide mineralization near McFauld's Lake in 2002[188]. This led to an exploration rush involving over 40 companies that culminated in the discovery of nickel, copper and platinum, as well as vanadium, titanium, gold, and exceptionally rich chromite mineralization. The Shield rocks hosting the mineralization are covered to the east by younger limestone of the Lowlands through or under which mining will need to penetrate.

McFauld's Lake lies on the western fringe of the James Bay Lowland, about 250 km west of Attawapiskat. The area has come to be informally called the "Ring of Fire" because of the arc-shaped surface pattern of highly magnetic rocks that host the mineralization (Fig. 22).

Discovery of the first (Noront's "Eagle One") copper and nickel deposit was followed by the "Blackbird One" and "Blackbird Two" chromium deposits, the only potential chromite mines in Canada. Current tonnage and grade assessments clearly indicate that McFauld's Lake is a world-class deposit. Chromite is normally mined in large open pits. If the deposit is brought into production it will be the only North American supply of chromium. Chromium is considered a strategic metal because the world supply is limited to very few countries and chromium is an essential ingredient in stainless steel.

Drilling and exploration in the McFauld's Lake area is currently supported out of Nakina, 300km to the south, where there is a paved airstrip, all-weather road, and railhead. At least two possible alternative infrastructure corridors from McFauld's Lake to Nakina have been discussed including one via Marten Falls (both are visible on Fig. 21; see section 3.2.3). If chromite is to be mined then large volume transportation such as an all season rail line or heavy duty road will be required[189]. Both the Albany and Attawapiskat rivers will need to be crossed either structurally or by some means such as ferries or barges. The same route can be envisaged for a power transmission line.

Assessing and limiting the environmental footprint of all mining, processing and transportation options will need to deal with the generation of acid mine drainage from extracting the copper and nickel sulphide ores and disposing of the waste rock in the McFauld's Lake area, as well as in any subsequent sulphide mineral discoveries. The chemical behaviour of chromium in the chromite and other minerals of the McFauld's Lake ore should also be established. It will be important to anticipate and understand any potentially complex chemical interactions between waters draining from mineralogically distinct mining operations and mingling in downstream wetland systems.

Current thinking foresees high-grade chromite ore crushed on-site and transported for processing at a mill located elsewhere. Less-rich ore would be crushed, milled and concentrated on-site and shipped with tailings disposed of on-site[189].

Companies involved in the "Ring of Fire" have estimated from 3–7 years for approval of an environmental assessment, including a closure plan. Interest is high from many points of view and there is considerable credibility to the perceived importance of the resource in the area.

Mining and Mercury Contamination

Mercury occurs naturally in some minerals and rocks[190], and thus has the potential for release in mining operations. It is generally found in mineral deposits that originated at low temperatures[191] and is not normally high in the types of high-temperature nickel sulphide or the chromite deposits in the McFauld's Lake area[192]. Nevertheless, careful documentation of the mercury concentrations in the ore minerals and potential mine waste rock wherever mining occurs, as well containment and monitoring, must be a very important requirement of all development activities. Comprehensive monitoring of water levels and water chemistry is also essential as a precursor to, and component of, mine development.

The mobilization of mercury, and conversion of inorganic to organic (methyl) mercury depends on local chemistry and environmental conditions. Dry, oxygenated conditions tend to favour demethylation, while the highest concentrations of methyl mercury occur in low-lying boggy areas, especially after long periods of warm weather with limited influx of oxygenated water. Open pit mines in wetland regions can result in water level changes, which in turn facilitate access for oxygen into previously anoxic sediments. When this occurs, sulphide will be oxidized to sulphate, liberating mercury and other metals. With subsequent rewetting, there is a potential for increased mercury methylation and transport to downstream locations. Since some fish species in the Far North are already at or exceed consumption guideline limits, such activities should be carefully monitored[193].

In high-sulphide ore areas, such as those containing copper and zinc deposits, acidic drainage from waste rock is caused by iron- and sulphur-oxidizing bacteria. Acid drainage is of concern both because it is toxic to aquatic organisms and because it increases the solubility of metals. Acidic waters are therefore likely to contain higher concentrations of metals, including mercury. Copper – zinc mines are potentially a source of mercury but host rocks and ores associated with a diamond or chromite mine are not known to produce acid or to contain mercury.

Industrial Minerals and Lignite

Various non-metallic mineral commodities have been the subject of exploration and feasibility studies over the years. These include: lignite (coal), gypsum, kaolin (fire clay), silica sand and high purity limestone and dolostone[194]. Most of these industrial mineral occurrences and deposits are located in the southern Moose River Basin. Lignite (brown coal) has been known since the seventeenth century in the Moose River Basin close to Onakawana on the Cochrane to Moosonee rail line[195] . The coal beds were drilled to test for the potential of coal bed methane in 2004 and 2005[196].

3.2.5 Forestry

As discussed in section 2.5, an estimated 6-7% of the Far North region includes forests with "commercial potential", concentrated in the southern tier of the region. However, no formal analysis has been undertaken and the economic viability of commercial forestry in this area is uncertain in light of low prevailing commodity costs. It is possible that with the development of transportation corridors for other purposes such as mining, or substantial increases in commodity prices related to forest utilization for bioenergy, larger areas of forest may become economically attractive from a resource extraction perspective. At present, no commercial

forest harvesting occurs, although the land use plan developed by the Pikangikum First Nation includes a forestry component.
As is generally the case, large-scale commercial forestry operations are certain to have significant impacts on forest structure and ecological function. These include large impacts on microclimate[197], hydrology[198], and the flux and storage of greenhouse gases[199], as well as effects on wildlife habitat. Due to the steep gradients in climate variables and soil characteristics in the Far North region, relevant ecological and biophysical processes will be quantitatively and qualitatively different from patterns observed in the current Area of Undertaking. Tree growth will generally be slower than in areas further south, and post-harvest regeneration less reliable. Ontario has no prior history of commercial harvest on permafrost, and in fact harvest of forest underlain by permafrost is not currently permitted in other provinces and territories of Canada. Commercial forestry development would also require extensions and improvements of existing road networks, the environmental impacts of which may be as great as those directly associated with harvesting activities (see section 3.2.3).

An additional special concern regarding forestry in the Far North region is potential impacts on mercury mobilization. In nearby regions of Québec, methyl and total mercury increased in downstream lakes following forest harvests, and increases in mercury levels in the entire food web from zooplankton to top predator fish, have been documented[200]. Forestry activities in peatlands may have particularly large effects on mercury mobilization that are qualitatively different than those found in other regions[201]. In addition, logging activities in the Boreal Shield region may be expected to have downstream impacts in the Hudson Bay Lowland where mercury levels is already exceptionally high.

If commercial forest harvesting is permitted in the region, mitigation measures to minimize environmental impacts should be undertaken in terms of both landscape-level planning and stand-level prescriptions. Landscape-level planning should specifically ensure regional protection of rare forest types and age classes, including late-seral ("old-growth") stands. Ecological function within harvested areas should be enhanced through use of structural retention harvest practices. Recent studies in operational areas immediately adjacent to the Far North region indicate that post-harvest mortality rates of residual trees can be very high (e.g., >50% for low densities of retained trees[202]). Retention harvests should therefore be based on large and spatially contiguous patches, and should include buffer zones near lakes and streams.

Due to the unique ecology of the Far North, any expansion of forest harvesting should be accompanied by targeted research work to better understand and mitigate impacts. Top priorities include assessment of harvest impacts on wildlife habitat, carbon dynamics, water quality and mercury dynamics, and assessments of post-harvest stand dynamics to assess long-term sustainability and develop appropriate silvicultural guidelines.

In summary, expansion of large-scale forestry into the Far North would likely have environmental impacts that are qualitatively different from those in areas further south. Economic gains for communities may also be marginal and unreliable given a highly variable timber commodity market. A very cautious approach should be taken to development within this sector to ensure that actions are consistent with conservation objectives of the *Far North Act*.

3.2.6 Wildlife and Freshwater Fish Harvest

Wildlife Harvest

Wildlife management (defined here as including monitoring and manipulation of population abundance and habitat) in the Far North is based on slightly different foundations for different animal groups. Wildlife and habitat management activities in Ontario have by and large focused on the Area of the Undertaking (south of the Far North boundary). For caribou, moose and deer, abundance and harvest management is based on a system of Wildlife Management Units (WMU), at a coarse scale of hundreds of square kilometres. Furbearers are monitored at the scale of registered traplines (tens to hundreds of square kilometres). Management of birds, on the other hand, is conducted at a range of scales. For the most part, management of both harvest and habitat for birds is at the population level, which is to say at the international (flyway) level. This is the case because most species are migratory. However, habitat management for both these and non-migratory species is also conducted at the site level through application of landscape guidelines. There are 8 WMUs in the Shield portion of the Far North, and 7 WMUs in the Hudson Bay Lowland. Frequency of population surveys for moose and caribou is greater in the southern Shield portion of the Far North (3-5 year cycle) than it is in the northern Hudson Bay Lowland portion (about a 10-20 year cycle). Aboriginal harvest of wildlife is governed by Treaty and Constitutional rights. Currently, there is no comprehensive process in place to measure harvest or integrate aboriginal harvest in the assessment of population sustainability.

Wildlife harvest in the Far North is primarily an activity of First Nations people. Harvest monitoring is sporadic and incomplete, although some communities have recently begun their own harvest surveys. In the Hudson Bay Lowland, harvest estimates for all groups of wildlife (furbearers, caribou, moose, waterfowl, other birds) were determined in the early 1980s[203]. In addition, waterfowl harvest in the Hudson Bay Lowlands was assessed about once per decade from the 1950s to the 1990s[204]. Waterfowl and caribou harvest is significant for local domestic economies here and at the scale of some goose populations and caribou ecotypes as well. Similar assessment of wildlife harvest in the boreal communities is less frequent. A formal inventory and assessment of harvest is recommended.

Fish Harvest

There are few quantitative data to assess the effects of harvest on fish populations in the Far North. Most past management activities and available data were associated with detecting fish species of interest for local use or tourist potential or for sampling fish for Mercury concentrations. For example, the OMOE contaminant monitoring program concentrated on analysis of contaminants in sportfish (walleye, pike, lake trout) collected during lake surveys conducted by OMNR during the 1970s and 1980s. In the Far North, most of the sampling occurred in large lakes in the Shield region; very little sampling occurred in streams or rivers in either the Shield or the Lowland area, and sampling in marine estuaries appears almost non-existent[205].

Mercury was and is the main contaminant of interest in these systems. For example, we know from other extensive surveys that 96% of Ontario walleye populations have some individuals with mercury levels

exceeding the 0.5 µg/g mercury consumption guideline[206]. The exceedances usually occur among the largest and oldest fish in a population of a top predator species. Even with the sparse data available for the Far North, it is perhaps wise to discourage frequent consumption of large older fish in unsurveyed lakes. Pregnant women and young children should completely avoid eating any fish with high mercury levels.
Far less information exists on contaminant levels in species such as whitefish and cisco, the prime subsistence food species of First Nations communities. These species are quite heavily used by coastal communities, where they are mainly harvested as migrating, anadromous fish moving into fresh water from James Bay or Hudson Bay[207]. Such fish that live mainly in salt water but migrate up rivers to spawn (including sea-run trout) tend to have lower mercury concentrations than landlocked fish[208]. In the absence of recent data it is likely safe to say that this food source is one of the highest quality fish foods found in the Far North, both nutritionally and with regard to minimal contaminants. Contaminant data should be sought for these species, and the potential for sustainable harvest and use of anadromous fish, possibly including limited commercial fishing of some stocks, could also be investigated.

3.2.7 Tourism

Tourism is a significant component of Northern Ontario's economy. In 2001, nature-based tourism (also known as resource-based tourism) accounted for 3% of total employment and over 17,000 jobs in all of northern Ontario north of the French River (i.e., not just the Far North). These are direct effects; indirect effects are much larger[209]. Resource-based tourism can generate considerable income for operators. In 2000, an estimated 600,000 tourist nights generated over $114 million for the operators of northern Ontario tourist sites not accessible by road. In 2004, 9.8 million same-day and overnight visitors spent over $1.7 billion on tourism-related expenditures in the North, including lodging, food and beverages, transportation, entertainment, and retail[210].

Northern Ontario attracts 20 percent of Canadian outdoor enthusiasts who travel within Ontario. Fly-in tourists typically pay 2 to 3 times more than for road-accessible experiences. American visitors are twice as likely to visit to hunt or fish (46 percent) than Canadian visitors (22 percent). Fishing is pursued on 66% of trips by Americans and 32% by Ontarians, while hunting is pursued by 2% and 3% of trips by American and Ontario tourists, respectively[211]. The ratio of anglers to hunters is 9 to 1 among Canadian visitors to the North. International tourists, in particular, seek opportunities to learn about Aboriginal cultures. In the Far North, remote tourism operations are currently concentrated in the Northwest area (Fig. 23).

Wildlife viewing and wilderness tourism have potential for growth in the Far North. Between 4000 and 6000 tourists visit Churchill, Manitoba annually to view polar bears[212]. Other major areas of interest for tourism in the north are road touring, outdoor adventure, hunting, fishing, and aurora borealis viewing[213]. Aboriginal communities are especially well positioned to create attractive tourism experiences in the future. Successful native tourism initiatives include the Kay-Nah-Chi-Wah-Nung Historical Centre, the Temagami Anishnabai Tipi Camp, the Cree Eco-Lodge in Moose Factory, and the Ojibway Historical Centre. Two formerly active tourism ventures, Eagle's Earth Cree and NONTA, are no longer in operation.

The success of remote tourism as an industry depends on maintaining the natural values that attract tourists to regions promoting nature-based activities. To date, there is little research on the nature and extent of remote tourism impacts on wilderness ecological integrity, although remote tourism is generally considered to be a lower-environmental impact activity as compared to other types of industrial development. Tourism

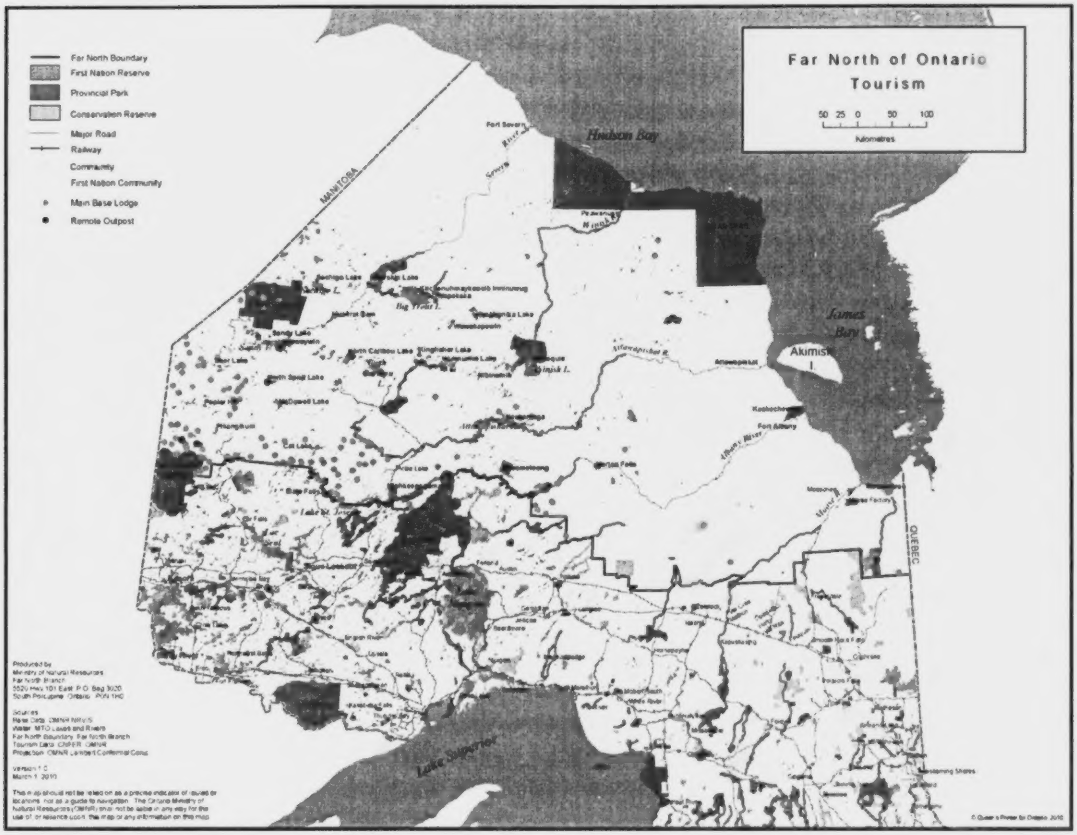


Figure 23. *Tourism in the Far North. Source: OMNR, Far North Branch, 2010*

activities that seriously disrupt ecosystem function and that occur over very large areas or affect rare ecosystems are most significant[214]. For example, fish stocking, particularly of introduced species, alters aquatic food webs and has been shown to be a contributing factor in the decline of native species[215]. Introduction of exotic invasive plant species can also result in changes to plant community dynamics over large areas[216]. Available studies show that the impacts of tourism are usually restricted to relatively small proportions of wilderness class parks, even in heavily visited areas[217].

Increased access, for instance by the building of all-weather roads, can lead to increased harvesting of wildlife and fish, altering the abundance, distribution and demographics of those populations. For example, in Ontario's boreal region, a population of lake trout in a small remote lake showed "rapid and severe" decline due to intense fishing pressure following the construction of a forest access road, with approximately 70% of the adult population removed in as little as five weeks[218]. Increased tourist traffic can also result in greater disturbance of wildlife during key periods such as breeding[219] and can result in avoidance of areas by wildlife causing changes in movement patterns and habitat use.

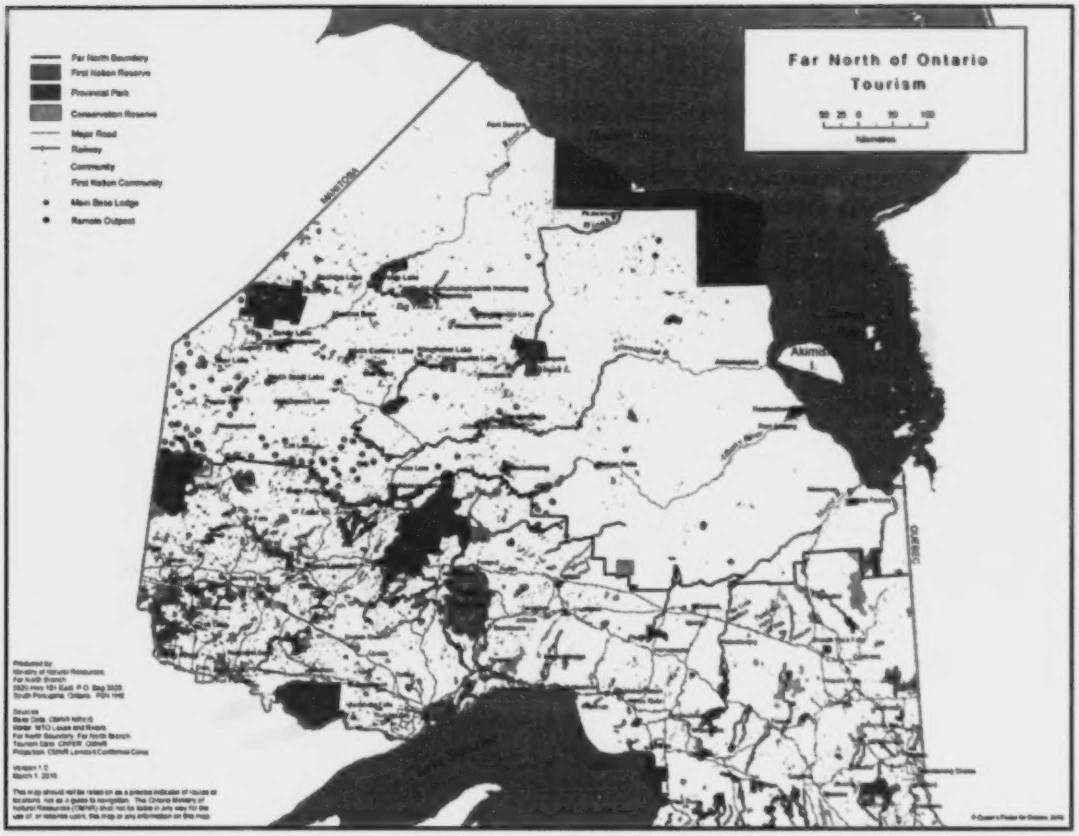


Figure 23. *Tourism in the Far North. Source: OMNR, Far North Branch, 2010*

activities that seriously disrupt ecosystem function and that occur over very large areas or affect rare ecosystems are most significant[214]. For example, fish stocking, particularly of introduced species, alters aquatic food webs and has been shown to be a contributing factor in the decline of native species[215]. Introduction of exotic invasive plant species can also result in changes to plant community dynamics over large areas[216]. Available studies show that the impacts of tourism are usually restricted to relatively small proportions of wilderness class parks, even in heavily visited areas[217].

Increased access, for instance by the building of all-weather roads, can lead to increased harvesting of wildlife and fish, altering the abundance, distribution and demographics of those populations. For example, in Ontario's boreal region, a population of lake trout in a small remote lake showed "rapid and severe" decline due to intense fishing pressure following the construction of a forest access road, with approximately 70% of the adult population removed in as little as five weeks[218]. Increased tourist traffic can also result in greater disturbance of wildlife during key periods such as breeding[219] and can result in avoidance of areas by wildlife causing changes in movement patterns and habitat use.

Remoteness is considered a key asset of the Far North for tourism. Other kinds of development activities, such as forestry, mining, hydro and wind power, and associated access infrastructure, have the potential to affect that quality of remoteness. Potential tourism revenues could be significantly affected by increased access, and will need to be considered as part of land use planning[220].

Infrastructure development associated with industrial activity also has the potential to reduce opportunities for star-gazing and impact wilderness values through increases in night-time lighting. Many organisms, particularly birds and insects, rely on the stars for navigation at night, particularly when migrating, and are attracted towards bright lights at night[221]. However, the extent of impact is dependent on the extent of infrastructure[222] and given the current lack of infrastructure and development combined with the relatively low number and size of communities distributed across the Far North, the potential for light pollution and the effects it may have on ecological systems at a broad scale is probably not significant compared to the other drivers discussed in this section. On the other hand, light pollution may be of particular concern in selected areas where infrastructure for specific industrial uses is concentrated.

4.0

APPROACHES TO LAND USE PLANNING

4.0 APPROACHES TO LAND USE PLANNING

Land use planning – initiated and led by First Nations – has been identified as a primary mechanism for realizing the Ontario government's stated objectives for the Far North. Current thinking about land use planning emphasizes the integration of social, environmental and economic values through the meaningful engagement of interested parties to make decisions about how the land and its resources should be managed and used in a coordinated and sustainable fashion[223] The capacity of the land to sustain desired uses and to maintain ecosystem integrity is a primary consideration, and this conservation-based approach to planning and resource use[224] is consistent with the Province's stated objectives for land use planning in the Far North[225].

The proposed *Far North Act* (Draft Bill 191, Oct. 22, 2009) provides for a "Far North land use strategy" to guide land use planning. The challenge of land use planning over this vast area is to ensure that community based land use plans take into account the broader-scale objectives and values of the Far North of Ontario, and that broad-scale objectives do not unnecessarily constrain community-level aspirations. We expect the Far North land use strategy to play a crucial role in balancing these challenges.

4.1 CONTEXT

The Far North is one of the world's largest, most intact ecological systems, reflecting a high level of ecological integrity and resilience to stress. In contrast, ecosystem degradation in most other parts of the world has led to declines in the number and distribution of species and ecosystems, the disruption of ecological processes that regulate these systems, and loss of ecosystem integrity and resilience. The common consequence of these changes is that resource-based economies become difficult or impossible to sustain, valued ecosystem services are compromised or lost, and socio-economic conditions decline. These are outcomes all wish to avoid in the Far North of Ontario.

With humans now appropriating more than 20% of the planet's primary productivity[236], large, intact landscapes like the Far North are globally rare[237]. Chapter 2 discussed the critical ecosystem services provided by the Far North in support of its own residents and wildlife species, and to areas far beyond its boundaries. The values of large, natural ecosystems have been globally recognized under the Convention on Biological Diversity, of which Canada is a signatory (see http://www.cbd.int/convention/convention.shtml).

The scale of planning for the Far North is unparalleled, as is the opportunity to undertake proactive planning that simultaneously considers development and protection over such a vast, intact area. The commitment in the Far North to plan for conservation before allocating for development has few precedents. The challenge is to develop a process that supports maintenance of the many values of the region while providing economic opportunities for local communities, including the sustainable development of mineral, forest and energy resources.

Previous sections have described the significant lack of environmental and resource information about the region. There are no basic surveys or inventories for most areas, let alone sufficient understanding of the relationships between species and ecosystems, or the potential for disturbance to alter those relationships[3*]. Traditional knowledge may address some of this shortfall, but is not yet expressed as a region-wide knowledge base. There are also major uncertainties in future conditions, both because of the dynamic nature of natural disturbance regimes, like fire, that shape the region and, most importantly, because of the looming spectre of climate change.

Conventional approaches to land use planning will not be effective in the Far North. An approach must be found that allows planning and management in a highly uncertain context, and balances community values and aspirations with those of the region as a whole. In section 4.2, we recommend a novel approach that we believe will meet these needs.

4.2 THE NEED FOR A NOVEL APPROACH

4.2.1 The Conservation-Matrix Model

Most land use and conservation planning takes place decades or centuries after resource development has begun and the landscape greatly altered. In such cases, the goal is often to secure the "best of what is left" by establishing protected areas to achieve biodiversity conservation and to maintain or restore ecological processes. Such remnants are generally roadless blocks of natural habitat or sites that have particular value in conserving unique ecological systems or species, but lack potential for industrial development. The resulting pattern is usually a dominant "matrix" of modified landscapes, in which conservation "islands" are embedded.

This approach must be reversed if the objectives of the Far North Act are to be met. Rather than having conservation islands within a matrix of developed lands, carefully-planned and managed development areas are needed within a matrix of conservation lands, some, but not all, of which could be formally designated as "protected". The objective of this approach, which has been called a "conservation-matrix" model[228], is to protect conservation values across the entire landscape. Given the unique size and condition of the Far North, the Panel believes that such an approach is not only warranted, but essential. As previous sections of this report have demonstrated, it will be essential to focus on the maintenance of ecological flows – the movements of organisms, water, and nutrients[229] – across landscapes. This in turn requires carrying out comprehensive and coordinated planning and management of all landscape components and uses.

---

*3 * Recent OMNR efforts to acquire basic ecological data for the region constitute an important step, but are far from complete and are not yet available to the public.*

On landscapes elsewhere, there has been a focus on protected areas as the result of landscape conversion, raising questions regarding "how much is enough?" – what percentage of lands must be protected in order to meet specific conservation goals, such as representation of environmental variation, and maintenance of target species? However, insufficient attention has been paid to addressing more ambitious goals related to ecological integrity, including the maintenance of ecologically functional populations of resident species, ecological processes, and ecosystem resilience. In the Far North of Ontario, where the vast majority of lands still maintain high conservation value, the question is instead "how much is too much?" In other words, how much development can be supported such that the natural and cultural values and integrity of the region are not compromised by such activities? The challenge of achieving this balance is further exacerbated by the changing climate and anticipated impacts on northern systems. Systematic planning using a conservation-matrix framework allows for a variety of land uses, ranging from strict protection to regulated resource development at appropriate scales. In this context, "protected areas" are areas that are placed off limits to industrial resource development.

Land use planning consistent with a conservation-matrix model focuses on identifying elements of the landscape that play four principal roles:

- **core protected areas** that serve as **landscape-level benchmarks**; these are the anchors of an interconnected conservation network, and serve as reference sites or controls for understanding the natural dynamics of ecosystems and their response to human activities. They are biodiversity "insurance policies" and buffers to environmental stressors that tend to compromise ecological integrity;
- additional **site-specific protected areas**; these capture values that may not be well represented within benchmark areas, such as additional areas of cultural significance, habitats or ecosystems of special scientific or conservation concern, identified "special elements" (e.g., rare species occurrences), and features that are key to maintaining connectivity across landscapes;
- **active management areas**, which are sites of relatively intense human activity, such as those associated with forestry, mining, or hydro-electric developments[230], and
- the remaining **conservation matrix**, the supportive environment within which less intense human activities, and roads and other linear corridors that connect development areas, are carefully planned and managed in an integrated fashion, so as not to erode other values.

Setting and meeting targets for protected areas will not, in isolation, ensure achievement of the ambitious objectives of the Far North Act. Managing the extent of the human footprint, including associated development activities, in a manner that does not compromise the supportive conservation values of landscapes as a whole, will also be required.

Land use planning for conservation landscapes must address the linkages between aquatic and terrestrial systems[231] as well as ecological systems that cross administrative or political boundaries. Such planning also requires that management approaches consider the total impacts of all development activities (e.g., mining, forestry, energy, roads, etc.), rather than piecemeal planning for individual development projects, and manage for the cumulative effects over space and time of multiple activities on the landscape[232]. This is especially important since climate change is likely to exacerbate the impacts of human activity and other natural drivers of change to increase the overall stress on northern ecosystems.

4.2.2 Uncertainty and the Need for Adaptive Management

The lack of experience with resource development in Far North of Ontario environments, and in the Hudson Bay Lowland in particular, warrants precaution due to myriad uncertainties. These include the direct and indirect effects of land use change on species and, above all, a lack of ability to predict how key ecological processes and ecosystem services will be altered as the climate changes. The dynamics of peatland, permafrost, riparian and estuarine systems, for example, are not well understood, and the response of individual species or species assemblages to landscape changes cannot be predicted with confidence. It is therefore difficult to develop a land use plan with confidence that it will achieve the objective of maintaining ecological integrity and, from social, cultural, and economic points of view, will sustain the environmental services and functions on which human communities ultimately depend. There is simply not enough knowledge of the system to predict ecological outcomes with certainty.

Under those circumstances, achieving sustainable outcomes in the Far North requires an adaptive approach. Adaptive management – an iterative process that allows us to adjust management strategies as our information about the system improves – is an effective means of dealing with the challenge of uncertainty and the attendant risks.

Adaptive management involves designing and implementing development activities in a systematic and incremental fashion, and carefully documenting effects at each stage, in order to reduce uncertainties in outcomes (see Section 4.4). In the context of the objectives for the Far North, development must be reconciled with the risk of unintended environmental consequences as activities expand in the region[233]. The burden of proof must be on development interests to demonstrate that their activities are ecologically and socially sustainable[234]. This will require continuous improvement of the information base and predictive tools to support the decision-making process.

Furthermore, adaptive management is a prerequisite when one of the most important drivers, climate change, is beyond local control. Careful consideration of climate change in the planning process will help to ensure that proposed development activities are appropriate for changing conditions.

4.3 PLANNING TO PROTECT ECOLOGICAL INTEGRITY

The overarching ecological objective of the *Far North Act* is "the maintenance of biological diversity, ecological processes and ecological functions, including the storage and sequestration of carbon in the Far North." (Section 6[3]). In the context of land management, this goal is most appropriately expressed as the maintenance of "ecological integrity", a concept that is usually expressed in terms of ecosystem structure and function. The following principles of ecological integrity can be used as benchmarks against which to gauge success in managing for resilience in the ecosystems of the Far North.

Native Species and Ecosystems Occur at Ecologically Functional Levels

One measure of long-term success in the Far North is conservation of the full range of native species, ecosystems and landscapes, and ecological processes (biodiversity). Biodiversity loss can result from many kinds of ecosystem stress, including habitat loss and degradation (the principal causes of species loss in Canada[235]), and air[236] and water[237] pollution. Conservation goals should be set to achieve, at minimum, the persistence of native species and ecosystems over a reasonable period of time in the face of known natural disturbances, such as wildfire and flooding. To maintain ecological integrity and resilience, ecosystems and populations should be maintained at natural levels of distribution and abundance, such that their functional roles and capacity to adapt are also supported[238].

Natural Disturbance Regimes Operate to Maintain Biological Diversity

Ecosystems are inherently dynamic, driven by disturbances such as fire, flooding, wind, and in some cases, consumption of vegetation by plant eaters. In the forested regions of the Far North, fire is a key driver, whereas flood events play a more prominent role in the dynamics of wetland, riverine and coastal ecosystems. Disturbance events create a mosaic of biological communities in time and space, and thus disturbance is an important determinant of regional biodiversity[239]. Maintenance of natural disturbance regimes across large landscapes contributes to the integrity and resilience of natural ecosystems. Alteration of natural disturbance regimes by human activities can have profound, and often unanticipated, effects on the structure and function of ecosystems[240]. Climate change has the potential to alter fire, insect and hydrological regimes over large areas, and thus to reduce ecosystem resilience, even in the absence of human activity.

Productivity, Decomposition and Nutrient Cycling Operate within Characteristic Limits

Most ecosystems are driven by primary productivity, the amount of organic matter produced by biological activity per unit area in a given time period. Ecosystem change can result from subtle shifts in productivity[241]. For example, pine forests exposed to airborne pollutants can experience stunted needle growth and premature loss[242]. In ecosystems stressed by acid precipitation, decomposition decreases[243]. Peatlands stressed by dewatering or increased rates of evapotranspiration (one of the expected consequences of climate change, as discussed in Chapter 3) have elevated decomposition rates that can also result in elevated emissions of greenhouse gases. In northern ecosystems, nutrient availability is a limiting factor, so rates of nutrient cycling are critical to ecosystem function. As ecosystems become stressed and lose integrity, they lose their ability to retain nutrients, and exhibit changes in rates of nutrient cycling and in the relative abundances of nutrient pools[244]. Productivity, decomposition and nutrient cycling operate within particular ranges for specific ecosystems, and the continuation of such rates within expected limits is a measure of ecosystem integrity.

Ecosystems are Resilient to Disturbance

Large intact landscapes are more resilient to disturbance than smaller ones, and those that have been eroded by human impacts. As discussed in section 3.1, large, natural ecosystems also play a critical role in storing and sequestering carbon and thus mitigating climate change[245]. The amount of carbon storage and sequestration varies between ecosystems and is influenced by various factors, including management practices and climate change itself. Ecosystems also influence the global climate through processes (e.g., changes in surface reflectivity) unrelated to carbon. Management approaches that maximize ecosystem resilience and minimize external stressors on biodiversity and ecosystem functions will assist in reducing other impacts that may otherwise accelerate ecosystem degradation and carbon release[246]. Foremost among the strategies proposed to mitigate deleterious affects of climate change and other stressors, and to facilitate adaptation, are securing large areas, reducing fragmentation and maintaining or increasing connectivity across large landscapes, conserving healthy and well-distributed populations of species in order to maintain genetic diversity, maintaining or creating favourable conditions in the landscape matrix outside protected areas, and pro-actively considering and planning for the potential effects of climate change in landscape management[247] .

4.4 ADAPTIVE MANAGEMENT AND THE SCIENCE OF SUSTAINABILITY

An overarching theme of this report is the uncertainty associated with planning in the Far North. Much of it comes from the difficulty of predicting the outcomes of management actions because our knowledge of the Far North's natural systems is incomplete, the systems themselves are dynamic, and the impacts of climate change are uncertain[248]. Indeed, these conditions increase the risk of failure with respect to achieving planning objectives at both local community and regional scales.

Section 4.2.2 introduced the concept of adaptive management, a structured process of learning that recognizes that unknowns and uncertainty exist in the course of achieving any natural resource management goals. Uncertainties can create barriers to effective decision-making, particularly where management concerns and scientific uncertainties are both high[249]. The complexity of natural ecosystems and the importance of spatial and temporal scales in understanding their dynamics pose many challenges to management, yet are essential for effective decision-making. Better understanding of these complex relationships will help to identify the appropriate balance between meeting human needs, addressing the reality that ecological systems have limits, and determining what management activities enable maintenance of ecosystem integrity[250]. Striking this balance would be a true measure of sustainability, and would reflect achievement of management objectives for the Far North.

The process of adaptive management can be represented as a continuous learning cycle, involving the key components of planning, doing, evaluating and adjusting (Fig. 24). Associated with each of these are a number of activities to support the identification and reduction of uncertainties, in order to improve decision-making. Central to the concept is the close integration of management, research and monitoring, where systems are not only carefully monitored but management responses are nimble enough to change course in response to the weight of evidence. Adaptive management involves controlled management experiments guided by current understanding of system dynamics. Highly uncertain outcomes associated with different policy options become strong candidates for experimentation. The results of experiments are used to inform adjustments to management strategies as necessary.

Implementing an adaptive management program in the Far North will require significant investment in information gathering and modelling tools to collect and synthesize information. A regional monitoring program and associated database management system should be established to collect and store information efficiently.

Decision-making systems should be collaborative and iterative, so management approaches can be adjusted as understanding of ecological systems improves. Adaptive management, and associated iterative policy review, are unfamiliar and may be uncomfortable concepts, both for communities and for governments. Yet the benefits of adaptive management are many, and include significant reductions in risk, dramatic increases in the transparency of decision-making, and a solid knowledge platform on which to base the choice of sustainable activities. In addition, the implementation and monitoring of structured management experiments create economic and employment opportunities[252] Finally, collaborative decision-making encourages capacity-building at the community level.

Throughout the planning process and in the decades ahead, both scientific and traditional knowledge can be used to improve understanding of the probable outcomes of different land use scenarios with respect

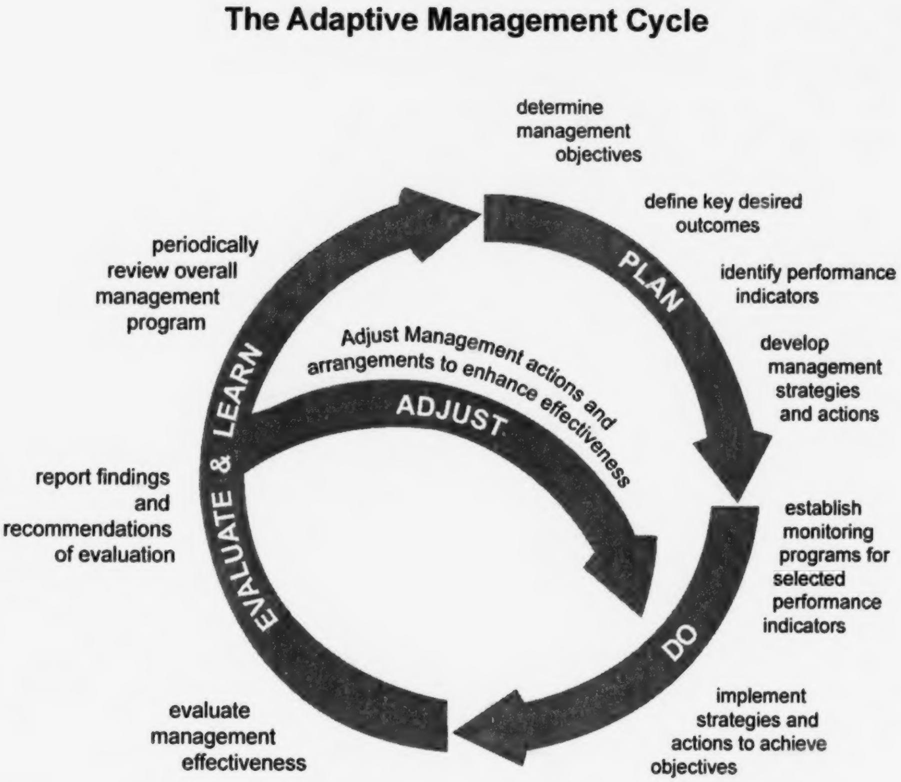

The Adaptive Management Cycle
determine management objectives
define key desired outcomes
PLAN
identify performance indicators
develop management strategies and actions
establish monitoring programs for selected performance indicators
DO
implement strategies and actions to achieve objectives
evaluate management effectiveness
EVALUATE & LEARN
report findings and recommendations of evaluation
periodically review overall management program
Adjust Management actions and arrangements to enhance effectiveness
ADJUST

Figure 24. *The adaptive management cycle. Source: Jones 2009*[251].

to achieving planning objectives[253]. In the meantime, caution is necessary for successful conservation of the Far North's globally important ecological systems and the social systems and communities that depend on them.

4.5 STRATEGIC CONSIDERATIONS

4.5.1 Planning Scale

At 452,000 km^2, the Far North of Ontario covers a huge area, and offers an unprecedented spatial scale at which to achieve the objective of maintaining ecological integrity. Yet planning will have to occur at multiple scales, to capture both broad-scale phenomena such as the movement of water and migratory species, and smaller scale ecological processes and localized features[254]. First Nation community views of conservation values will be important determinants of local land use planning, and may often correspond well with ecologically-based assessments[255]. However, local planning initiatives should be conducted with knowledge and consideration of broader ecological patterns and processes, as well as the cross-scale interactions that link ecosystems across regional landscapes[256]. These considerations underscore the importance of applying an approach that addresses different spatial scales and levels of biological organization, often referred to as a "coarse-filter/ fine-filter" approach[257].

The following sections describe the landscape properties and planning principles that will be necessary for a Far North Land Use Strategy that provides guidance for the development of community based plans.

4.5.2 Units for Conservation Planning

Ecological units, or areas with similar environments and species, usually serve as the basis for conservation planning[258]. These can be units based on soil type and vegetation cover[259], or natural systems such as drainage basins (watersheds or waterscapes)[260]. A multi-scale, integrated hydrology and watershed mapping project is currently underway in the Far North, which could provide a strong foundation for conservation planning in the region. Watershed-based units related to a hydrological network offer the advantage of addressing issues across a hierarchy of scales with a single dataset. More broadly, natural units can be helpful in understanding the distribution of ecological properties within and across planning areas (e.g., neighbouring communities). They can also help ensure appropriate representation of environmental variation within core protected areas across the region, assist in identifying locally significant ecological features, and contribute to the maintenance of connectivity of terrestrial and aquatic systems across planning areas. There are well understood GIS management and planning tools available for application to natural planning areas, including those based on watersheds and water flows.

Earlier sections have emphasized the importance of water flows in connecting ecosystems, but such connections are also important in considering the upstream and downstream effects of land use decisions on the quantity and quality of water. Protecting drinking water sources for communities will therefore require an understanding of local water processes, for example in traditional use areas, and also how they are affected by activities in the broader region. In many cases, it will therefore be important to coordinate planning across community boundaries.

4.5.3 Connectivity

Ecological integrity depends on maintaining ecological connectivity, such that wildlife populations, trophic relationships, natural disturbances, and water flows remain functional at multiple scales[261]. For example, the maintenance of viable populations of plants and animals requires that landscapes support movements of individuals for dispersal and gene flow, and maintenance of meta-populations (neighbouring and interacting populations of the same species).

The Far North represents an ecologically intact situation that supports natural levels of connectivity. A fundamental goal of land use planning should therefore be to ensure that the region does not lose this attribute. Connectivity contributes to ecosystem resilience by increasing stability across scales. While protected areas are an important component of a regional conservation network, the larger strategy must have as a primary goal the maintenance of connectivity across all components of local landscapes, as well as the broader Far North region. This is a key role of the conservation matrix.

The value of connectivity can be understood when contemplating the consequences of its loss. In terrestrial systems, as human development proceeds, landscape transformation typically begins with loss of native vegetation cover and proceeds to fragmentation of remaining native cover into a number of "smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original"[262]. At the outset of this process, habitat loss is the most important driver of impacts to ecological integrity, but this later shifts to the configuration and connectivity of remaining habitat[263]. Habitat loss and loss of connectivity interact and can result in fundamental ecosystem changes, eroding the landscape's long-term capacity to support populations and ecological processes. Thus, fragmentation of regional landscapes is recognized as a major threat to biological diversity throughout the world[264].

A significant challenge in managing to maintain connectivity in landscapes subject to land use changes is that connectivity of ecological processes and habitat connectivity for species are both difficult to measure. Human perceptions of the landscape will be governed by physical connectedness (of forest cover for example), whereas organisms will view the relative connectivity of a given landscape in species-specific ways[265]. The key will therefore be to manage for conditions that are least likely to disrupt natural patterns of connectivity, for example by maintaining the amount and distribution of land cover types well within the range of natural variation, as well as avoiding disruption of water flows by adopting a watershed-based approach to planning, and perhaps by focusing on the needs of habitat specialists and species with large area or migratory requirements[266]. This approach is discussed in more detail in section 4.5.6.

4.5.4 Thresholds of Landscape Change

Planning for conservation and sustainable development requires an understanding of "thresholds" in the extent and intensity of change that can be tolerated by ecosystem components (e.g., species or ecological processes), that when crossed can result in sudden shifts in systems[267]. Near such thresholds, small changes, for example, in habitat loss or fragmentation, input of contaminants, or increases in carbon dioxide, may produce disproportionately large ecosystem responses[268]. In planning for the Far North, it must especially be acknowledged that system responses to landscape modification may have critical zones where rapid change can occur, because the changes that result may be irreversible[269].

Much of what is understood about ecological thresholds has been gathered retrospectively; that is, the threshold has only been discovered once the line has been crossed[270]. Some relevant examples of documented threshold effects include:

- Habitat loss. Species that require interior forest conditions are unable to persist in landscapes with intact habitat patches that are below a certain size (forest-dependent birds[271]) or that have exceeded an overall level of habitat loss (American marten[272]).

- Overall disturbance. Disturbance-sensitive species exhibit recruitment failure once a certain percentage of their population range has been cleared through natural and anthropogenic disturbance (boreal forest caribou[273]).
- Roads. Species are unable to persist in landscapes characterized by critical density of roads (wolves[274]), or within a certain distance from roads (caribou[275]).

It is difficult to anticipate in advance the nature and likelihood of thresholds[276], which are typically context-specific, species and process-specific, and scale-dependent. Analysis and decision making are further complicated when multiple drivers (e.g., road density, traffic volume, and distance from roads) act in a cumulative fashion[277].

Because most environmental laws define a threshold between legal and illegal activities, the ecological threshold concept might seem attractive as a regulatory instrument[278]. However legal systems are characteristically not flexible, and thresholds may be viewed as "magic numbers", or even as minimum standards, providing an invitation for agents of landscape change to go "right to the limit". Because of incomplete understanding of the variability and response of natural systems, such an approach could easily push the system past an ecologically tipping point even when the law is being adhered to. In addition, because both social and ecological systems are complex, dynamic and adapting, related thresholds are themselves dynamic.

In the Far North, multiple influences on the landscape, including natural stressors such as fire and climate change, will continue to challenge the operational implementation of threshold concepts. Nevertheless, every effort should be made to anticipate and prevent ecological tipping points; to do otherwise would put the resilience of this intact ecosystem at risk. Enough is known about certain responses to suggest precautionary limits to human-induced change using sensitive elements of the system, such as species like boreal caribou (total landscape disturbance[279]) and lake trout (access to lakes[280]).

4.5.5 Protected Areas and Land Use

The term "protected area" has been the subject of considerable debate, both in scientific circles and in decision-making contexts. For the purposes of this discussion, we have adopted the International Union for the Conservation of Nature (IUCN)'s definition of a protected area as *"a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values"*[281]. So while planning for conservation landscapes is intended to maintain ecological integrity at a broad scale, the primary and explicit objective of protected areas is to consider these values above all else. For this reason, protected areas play an important role even in largely intact landscapes, such as in the Far North of Ontario.

Protected areas can act as biodiversity reservoirs, buffers to environmental change, and as benchmarks for human activities in portions of the landscape subject to development[282]. Outside protected areas, other goals may assume a greater priority, for example in areas of active industrial development. In addition to the conservation of nature, protected areas can play a key role in supporting the continuation of traditional activities such as hunting, trapping, and harvest of traditional materials[4*]; tourism and recreation; job creation; conserving built heritage; and providing a place for personal connection to wild nature.

The IUCN recognizes six categories of protected areas, corresponding to the degree to which long-term conservation of nature and ecosystem services is prioritized against other values (Table 5). Some examples of categories of existing protected areas in Ontario are provided, but others continue to emerge through aboriginal and community based planning processes (e.g., Whitefeather Forest).

---

*4 * Traditional activities will continue regardless of land designation.*

Table 5. IUCN definitions for categories of protected areas, after Dudley (2008) with examples in the Far North recognized in legislation.

Category	Title	Description	Far North Example
Ia	Strict nature reserve	Strictly protected areas set aside to protect biodiversity and also possibly geological/ geomorphological features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.	Sedgman Lake Provincial Nature Reserve
Ib	Wilderness area	Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.	Opasquia Provincial Park
II	National park	Large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area. Provide a foundation for environmentally and culturally compatible spiritual, scientific, education, recreational and visitor opportunities.	Polar Bear Provincial Park

Table 5. IUCN definitions for categories of protected areas, after Dudley (2008) with examples in the Far North recognized in legislation.

Category	Title	Description	Far North Example
Ia	Strict nature reserve	Strictly protected areas set aside to protect biodiversity and also possibly geological/ geomorphological features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.	Sedgman Lake Provincial Nature Reserve
Ib	Wilderness area	Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.	Opasquia Provincial Park
II	National park	Large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area. Provide a foundation for environmentally and culturally compatible spiritual, scientific, education, recreational and visitor opportunities.	Polar Bear Provincial Park

Category	Title	Description	Far North Example
III	Natural monument or feature	Set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. Generally quite small areas and often have high visitor value and monitoring.	Sutton Lake Gorge Wilderness Area
IV	Habitat/species management area	Protect particular species or habitats, and management reflects this priority. May need regular, active interventions to address requirements of particular species or to maintain habitats	Moose River Migratory Bird Sanctuary
V	Protected landscape	Interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value. safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.	No example in Northern Ontario
VI	Protected area with sustainable use of natural	Conserve ecosystems and habitats, together with associated cultural values and traditional natural resource management systems. generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.	No example in Northern Ontario

Category	Title	Description	Far North Example
III	Natural monument or feature	Set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. Generally quite small areas and often have high visitor value and monitoring.	Sutton Lake Gorge Wilderness Area
IV	Habitat/species management area	Protect particular species or habitats, and management reflects this priority. May need regular, active interventions to address requirements of particular species or to maintain habitats	Moose River Migratory Bird Sanctuary
V	Protected landscape	Interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value. safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.	No example in Northern Ontario
VI	Protected area with sustainable use of natural	Conserve ecosystems and habitats, together with associated cultural values and traditional natural resource management systems. generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.	No example in Northern Ontario

A high degree of intactness is not necessary to satisfy every conservation value, whether ecological or cultural, but large, ecologically-intact areas like the Far North are globally rare[283]. Elsewhere in the world, the ability to achieve some conservation goals, and to benchmark ecological conditions such that natural dynamics can be clearly distinguished from human-induced change, has been lost.

In the Far North, there exists a nationally and globally significant opportunity to establish ecological benchmarks at the system level. System-level benchmarks are ecologically intact areas that are representative of natural environmental variation, including vegetation communities and productivity gradients, and are sufficiently large to maintain key ecological processes and support natural ecosystem dynamics. For example, in the Far North, characteristics of the fire regime can be used to guide the minimum size required to maintain vegetation communities over time in a dynamic system[284]; this would be a useful starting point for evaluating additional requirements based on other considerations (e.g., habitat needs of focal species). Similarly, watersheds can be designated as conservation units, for the purpose of assessing and protecting hydrologic connectivity, and for building candidate benchmark areas out from headwaters, along stream networks[285].

A preliminary assessment of potential benchmark areas across boreal regions of Canada suggests that the minimum area required to accommodate the characteristic fire disturbance regime (the so called "minimum dynamic area") in the Far North is in the range of 1–1.5 million ha[286]. This implies that representative benchmark areas should be at least this size. However, the needs of habitat specialists and wide-ranging species, as well the effects of changing climate on future fire regimes, are likely to increase this minimum size requirement significantly. The same assessment also illustrates that there are many other options for establishing benchmark areas in the Far North, providing flexibility for land use planning aimed at achieving multiple objectives.

Benchmarks serve an important purpose as reference sites for the detection of change in ecosystem composition and function due to human activities. They allow a distinction to be made between important development-related changes and natural fluctuations. But to be effective, individual benchmark areas must be large, and the system of benchmarks must capture the full range of natural ecological systems and ecosystem variability that exist in the region. This has rarely been the case in Canada. For example, 27% of Canada's northern Arctic Cordillera ecozone falls in protected areas, but the productive Mixed Wood Plains ecozone of southern Ontario and Québec has only 1.6% protected[287]. Moreover, the vast majority of protected areas in Canada and globally are too small to meet their long-term conservation objectives. Of the 3500 protected areas in Canada, 90% are less than 100 km^2 [288]. Small protected areas require a great deal of active management and on-going restoration to maintain their ecological values. It is therefore far more effective to establish very large protected areas that serve as system-level benchmarks, and also provide important ecosystem services, including carbon storage, without management intervention[289].

4.5.6 Planning for Specific Ecosystems and Species

Ecosystems must maintain the ability to renew and reorganize following disturbance, and this in turn relies on the persistence of characteristic vegetation and functional groups of species[290]. Broad ecosystem types, vegetation communities and individual species or species groups are all useful tools in the design of conservation landscapes (land use planning) and to set monitoring targets for the evaluation of ecological integrity and resilience.

Representation of environmental variation has been used extensively as a coarse-filter approach to conservation[291]. The general assumption is that capturing the variety of ecosystems and environmental variation in a given planning area (the full range of vegetation types, climatic and geological characteristics, e.g., soils, elevation, topography), will conserve the component habitats and species within those ecosystems. In the past, protected areas planning in Ontario has been founded on such an approach, as depicted in Figure 13. Requiring that core protected areas include, at a minimum, proportional representation of all ecosystems and associated gradients in environmental conditions may also facilitate the adaptation of plant and animal communities to climate change, given that the areas are of sufficient size and are adequately connected to support various adaptation strategies.

In addition to the goal of representing all ecosystems, there are particular ecosystems in the Far North that should receive particular attention. These include, but are not limited to, the following:

- **Peatlands** – As noted in previous sections, the wetlands of the Far North are among the most extensive on earth, and they are also the densest carbon-storage ecosystems and the densest water-retention ecosystems in Ontario (see section 2.4).
- **Permafrost Ecosystems** – In the Far North, continuous permafrost is extensive, and is expressed as mineral permafrost ecosystems in the vicinity of Hudson Bay, and as extensive peatland and tundra permafrost ecosystems extending as much as fifty kilometres inland. Beyond this, and as far south as the southern James Bay lowland, discontinuous permafrost persists in deeper peatlands of various types (see section 2.2).
- **Coastal Wetlands** – Along James Bay and Hudson Bay are some of the most productive subarctic wetland habitats in Canada, providing breeding, staging, feeding and migratory habitats for some of the most abundant waterfowl and shorebird populations in Canada (see sections 2.3 and 2.4).
- **Major Rivers and River Estuaries** – The Severn, Winisk, Ekwan, Attawapiskat, Albany and Moose Rivers and their coastal estuaries are only the largest and most obvious of high-diversity, aquatic-terrestrial corridors and discharge ecosystems in the region (see section 2.3).
- **Disjunct vegetation communities**. A variety of remote occurrences of vegetation communities occur throughout the Far North, as products of past climate change, such as elm lowlands disjunct to the north, and arctic-alpine communities disjunct to the south.
- **Remote Forested Uplands** – A number of remote forests occur as upland islands within the Hudson Bay Lowland on raised glaciofluvial deposits. These anomalous occurrences are living laboratories of potential interest for their genetics, their isolation from forest pathogens, etc. (section 2.5).
- **Concentrations of Fish and Wildlife** – A range of species congregate in denser numbers at sites where conservation and appropriate management are critical, such as areas for breeding, spawning, staging, migrating, calving, etc. (see section 2.7).
- **Headwaters** – Headwaters play a disproportionate role in maintaining the ecological integrity of downstream aquatic and terrestrial ecosystems[292]. They are the primary interface between upland and riparian areas and the overall stream network[293], and are the source of water, sediments, dissolved organic carbon, woody debris, nutrients, and food (i.e., aquatic and terrestrial invertebrates)[294], refugia, and source areas for biodiversity[295]. All of these functions influence the structure, function, productivity, and biodiversity of downstream ecosystems[296]. The degradation and loss of headwaters and their connections to downstream ecosystems have been shown to threaten the ecological integrity of entire river networks[297].

Coarse-filter approaches such as these may be helpful in identifying the basic building blocks of conservation areas[298], but are of limited use in defining the amount (quantity and size) and pattern (connectivity) of different landscape elements[299]. Many such issues are most appropriately addressed in reference to the needs of the species. The Far North supports many species, so it will be necessary to select a subset on which to focus conservation planning and monitoring efforts.

In the Far North, species with the following characteristics could serve as appropriate "focal species"[300]:

1. Space-demanding;
2. Vulnerable to human disturbance and other threatening processes (e.g., climate change and land use change);
3. Low reproductive capacity, i.e., populations have a difficult time recovering (due to low reproductive rates, for example), following decreases in numbers; and
4. Of particular socio-economic or cultural importance.

In most conventional conservation management, interventions tend to be focused on the species itself with minimal regard to the system of which they are part[301]. As a result, attention tends to be prioritized on those species at greatest risk of extinction[302], often with an emphasis on rare or geographically restricted organisms[303]. An alternative approach is to focus on species for which the Far North constitutes an important stronghold, and that have a demonstrated vulnerability to the types of land use changes that are likely to become more prevalent. Table 6 presents a suite of candidate focal species that could be used for various scales of land use planning in the Far North.

Ideally, the suite of focal species should include those whose needs encompass the full variety of major terrestrial and aquatic habitats and threats[304], which play critical roles in shaping ecosystem processes[305], and/or are most sensitive to the dominant threats[306]. It is generally assumed that because the most demanding species are selected, a landscape designed and managed to meet their needs will encompass the requirements of other species with similar or lesser sensitivities to the same suite of threats[307]. Likewise, because focal species are generally among the first to disappear in response to certain levels of disturbance, monitoring efforts should be designed with sufficient statistical power to detect early signs of ecosystem degradation.

The information gaps are enormous regarding the status and distribution of most species residing in Far North of Ontario. Even some species that are well-known in other parts of their range (e.g., moose, boreal birds), have until recently received little or no survey or monitoring attention in the Far North. At the scale of traditional use areas, aboriginal traditional knowledge regarding location of important areas for wildlife, movement corridors, and experience related to the vulnerability of certain species to disturbance will be crucial to filling knowledge and information gaps.

Table 6. Traits and examples of focal species to support land use planning in the Far North

Traits	Role in Land Use Planning/Management	Species Examples
Specialized habitat requirements	Identify areas of importance for protection; monitor condition of such areas.	Lake trout; yellow rail, lesser and greater scaup and scoters 47 plant species restricted to Hudson Bay maritime coast
Regular aggregations (breeding, calving, spawning, staging, etc.)	Identify areas of importance for protection; monitor condition of such areas.	Caribou (migratory ecotype); yellow rail, hudsonian godwit, sharp-tailed grouse; lake sturgeon
Space-demanding	Size of protected areas, Connectivity	Caribou, wolverine, polar bear
Regular movement routes, migratory flyways	Identify areas of importance for protection, Connectivity	Migratory waterfowl and shorebirds; caribou, wolverine
Sensitive to disruption of hydrological connectivity	Inform hydrological connectivity	Lake sturgeon, brook trout
Known relationship between population condition and habitat condition (extent of disturbance)	Identify thresholds of disturbance for land use planning; monitor cumulative impacts	Caribou, American marten; lake trout

Traits	Role in Land Use Planning/Management	Species Examples
Sensitive to changing climate	Monitoring climate change	Polar bear; brook trout; black spruce
Far North of Ontario represents core breeding areas and Ontario has major responsibility; some are exhibiting declining trends outside of Far North of Ontario.	Identify forest and wetland areas for which broad protection and monitoring are required for community of species	Hudsonian godwit, yellow rail, boreal passerine birds: rusty blackbird, Nelson's sparrow, Smith's longspur, Connecticut warbler, orange-crowned warbler, palm warbler and white-crowned sparrow.
Heightened risk of overexploitation due to life history (e.g., Late maturity, low fecundity)	Monitor overexploitation	Caribou, wolverine; lake sturgeon, lake trout
Vulnerable to competition, hybridization	Monitor impacts of invasive or weedy species into the Far North	Gray wolves; lake trout

4.5.7 Comprehensive Landscape Management

This discussion has demonstrated that implementation of a conservation matrix model in the Far North will require comprehensive landscape management through integrated planning of all activities and land uses. The intent is to avoid piecemeal planning and decision-making about individual projects or sites, and focus instead on ecological flows, including movements of individual organisms, water, and nutrients, across the region[308]. Put another way, maintenance of ecological integrity requires that the landscape matrix play a strong supporting conservation role. The process of managing the extent of the human footprint and associated development activities in a manner that does not compromise the supportive conservation value of the matrix will be as important as the designation of protected areas[309].

The Far North supports many resources of interest to humans – forests, minerals, energy, food and recreational opportunities, among others. Although the footprint associated with pursuit of these resources can differ widely, they share a common attribute: the need for access. Clearly, roads have great utility to

Table 6. Traits and examples of focal species to support land use planning in the Far North

Traits	Role in Land Use Planning/Management	Species Examples
Specialized habitat requirements	Identify areas of importance for protection; monitor condition of such areas.	Lake trout; yellow rail, lesser and greater scaup and scoters 47 plant species restricted to Hudson Bay maritime coast
Regular aggregations (breeding, calving, spawning, staging, etc.)	Identify areas of importance for protection; monitor condition of such areas.	Caribou (migratory ecotype); yellow rail, hudsonian godwit, sharp-tailed grouse; lake sturgeon
Space-demanding	Size of protected areas, Connectivity	Caribou, wolverine, polar bear
Regular movement routes, migratory flyways	Identify areas of importance for protection, Connectivity	Migratory waterfowl and shorebirds; caribou, wolverine
Sensitive to disruption of hydrological connectivity	Inform hydrological connectivity	Lake sturgeon, brook trout
Known relationship between population condition and habitat condition (extent of disturbance)	Identify thresholds of disturbance for land use planning; monitor cumulative impacts	Caribou, American marten; lake trout

Traits	Role in Land Use Planning/Management	Species Examples
Sensitive to changing climate	Monitoring climate change	Polar bear; brook trout; black spruce
Far North of Ontario represents core breeding areas and Ontario has major responsibility; some are exhibiting declining trends outside of Far North of Ontario.	Identify forest and wetland areas for which broad protection and monitoring are required for community of species	Hudsonian godwit, yellow rail, boreal passerine birds: rusty blackbird, Nelson's sparrow, Smith's longspur, Connecticut warbler, orange-crowned warbler, palm warbler and white-crowned sparrow.
Heightened risk of overexploitation due to life history (e.g., Late maturity, low fecundity)	Monitor overexploitation	Caribou, wolverine; lake sturgeon, lake trout
Vulnerable to competition, hybridization	Monitor impacts of invasive or weedy species into the Far North	Gray wolves; lake trout

4.5.7 Comprehensive Landscape Management

This discussion has demonstrated that implementation of a conservation matrix model in the Far North will require comprehensive landscape management through integrated planning of all activities and land uses. The intent is to avoid piecemeal planning and decision-making about individual projects or sites, and focus instead on ecological flows, including movements of individual organisms, water, and nutrients, across the region[308]. Put another way, maintenance of ecological integrity requires that the landscape matrix play a strong supporting conservation role. The process of managing the extent of the human footprint and associated development activities in a manner that does not compromise the supportive conservation value of the matrix will be as important as the designation of protected areas[309].

The Far North supports many resources of interest to humans – forests, minerals, energy, food and recreational opportunities, among others. Although the footprint associated with pursuit of these resources can differ widely, they share a common attribute: the need for access. Clearly, roads have great utility to humans but, as discussed in section 3.2.3, their effects extend well beyond their role as conduits to and through remote areas. Access will be a primary driver of change in the Far North, through both direct and indirect means. The very limited access of the region is an important contributor to its ecological integrity. Given the desire to increase access to communities and resources, and the reality that activities associated with this are proceeding in advance of community based land use planning, a fundamental consideration in maintaining a conservation matrix, and more broadly in preventing the pre-emption of land use options, is a carefully planned road network. A well thought out access plan is a key element of the Far North land use strategy.

Achieving comprehensive landscape management requires a systematic and integrated approach that addresses the linkages necessary between different scales of land use planning, and places the overall process within a framework guided by adaptive management (Figure 25). Throughout this chapter we have suggested various means of achieving this, some of which are further elaborated in the Recommendations section of this report.

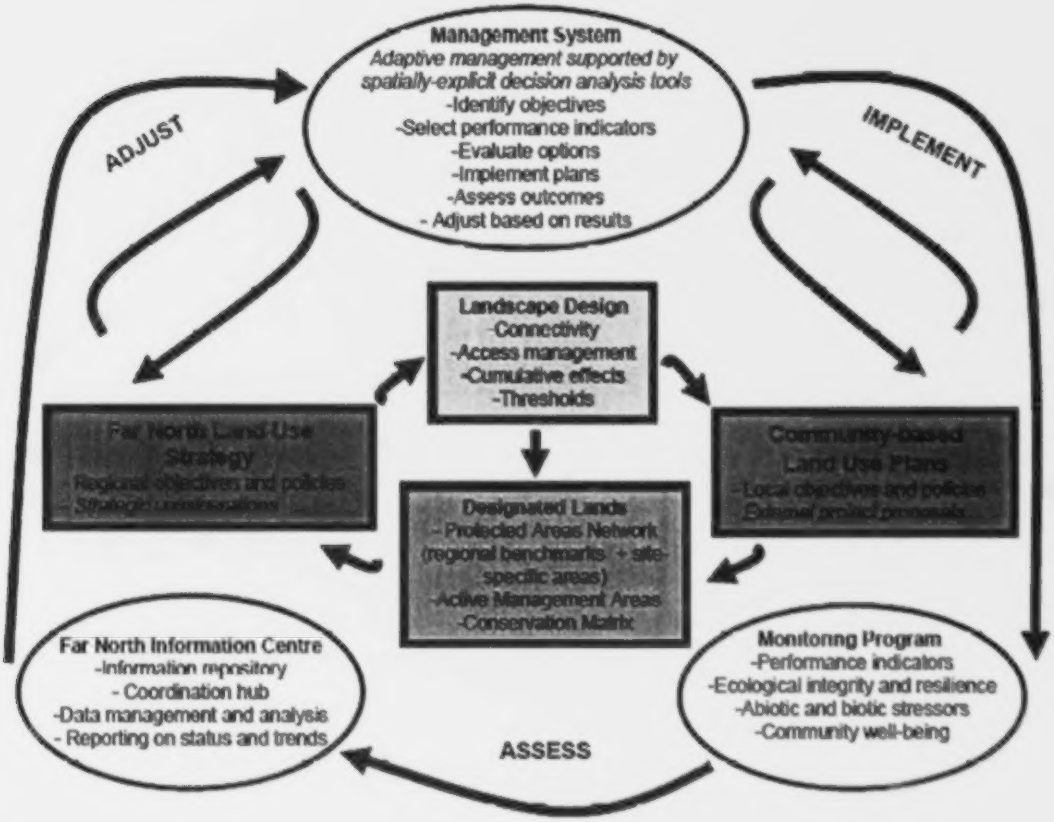

Management System
Adaptive management supported by spatially-explicit decision analysis tools
-Identify objectives
-Select performance indicators
-Evaluate options
-Implement plans
-Assess outcomes
- Adjust based on results
ADJUST
IMPLEMENT
Landscape Design
-Connectivity
-Access management
-Cumulative effects
-Thresholds
Far North Land Use Strategy
- Regional objectives and policies
- Strategic considerations
Community-based Land Use Plans
- Local objectives and policies
- External project proposals
Designated Lands
- Protected Areas Network (regional benchmarks + site-specific areas)
-Active Management Areas
-Conservation Matrix
Far North Information Centre
-Information repository
- Coordination hub
-Data management and analysis
- Reporting on status and trends
Monitoring Program
-Performance indicators
-Ecological integrity and resilience
-Abiotic and biotic stressors
-Community well-being
ASSESS

Figure 25. *A framework for comprehensive landscape management*

humans but, as discussed in section 3.2.3, their effects extend well beyond their role as conduits to and through remote areas. Access will be a primary driver of change in the Far North, through both direct and indirect means. The very limited access of the region is an important contributor to its ecological integrity. Given the desire to increase access to communities and resources, and the reality that activities associated with this are proceeding in advance of community based land use planning, a fundamental consideration in maintaining a conservation matrix, and more broadly in preventing the pre-emption of land use options, is a carefully planned road network. A well thought out access plan is a key element of the Far North land use strategy.

Achieving comprehensive landscape management requires a systematic and integrated approach that addresses the linkages necessary between different scales of land use planning, and places the overall process within a framework guided by adaptive management (Figure 25). Throughout this chapter we have suggested various means of achieving this, some of which are further elaborated in the Recommendations section of this report.

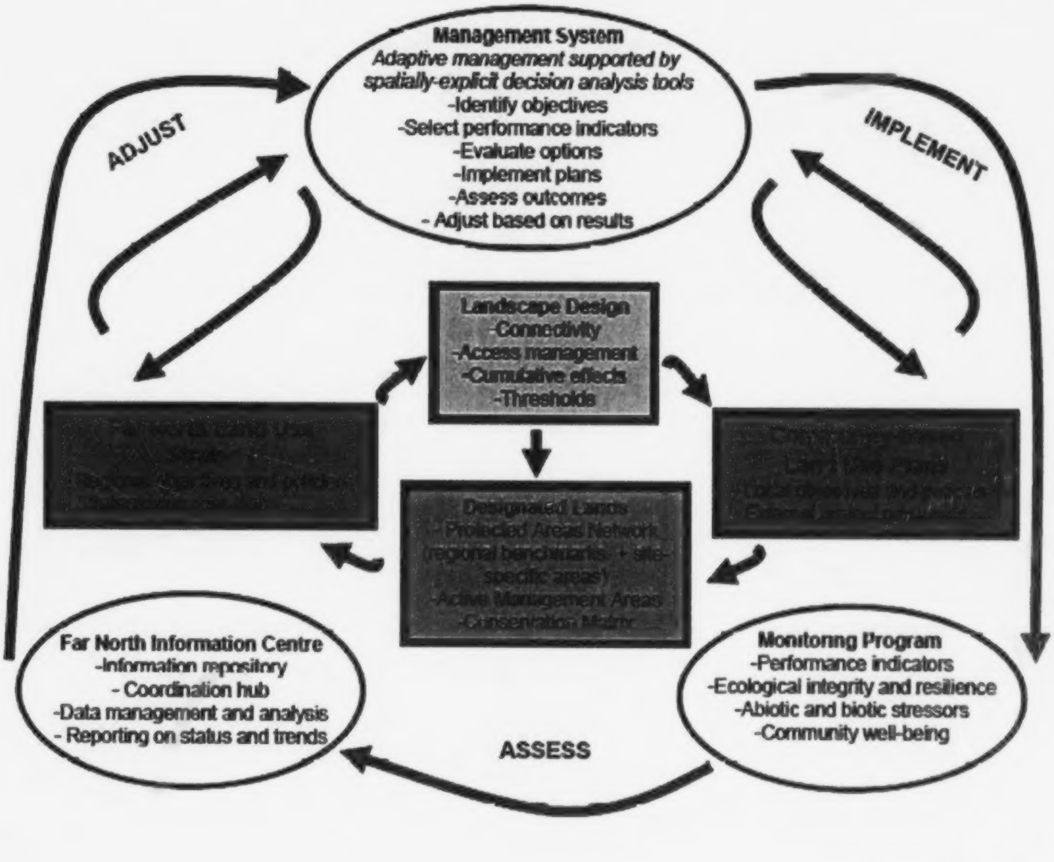

Management System
Adaptive management supported by spatially-explicit decision analysis tools
-Identify objectives
-Select performance indicators
-Evaluate options
-Implement plans
-Assess outcomes
- Adjust based on results
ADJUST
IMPLEMENT
Landscape Design
-Connectivity
-Access management
-Cumulative effects
-Thresholds
Far North Land Use
Strategy
Regional objectives and policies
Community Based
Land Use Plans
Local objectives and policies
Designated Lands
- Protected Areas Network (regional benchmarks + site-specific areas)
-Active Management Areas
-Conservation Matrix
Far North Information Centre
-Information repository
- Coordination hub
-Data management and analysis
- Reporting on status and trends
Monitoring Program
-Performance indicators
-Ecological integrity and resilience
-Abiotic and biotic stressors
-Community well-being
ASSESS

Figure 25. *A framework for comprehensive landscape management*

5.0

RECOMMENDATIONS

CHAPTER 5: RECOMMENDATIONS

The Far North of Ontario is one of the world's largest, most intact ecological systems, reflecting a high level of ecological integrity and providing ecosystem services far beyond its borders. Partners in planning have a responsibility to advance Far North development in a manner responsive to community based planning, while meeting regional and international expectations and commitments. This requires the maintenance of biological diversity and ecological functions, including carbon storage and sequestration, through the conservation of natural ecosystems. Achieving these goals through a land use planning process will require a novel approach, one that has as its fundamental organizing principle the maintenance of ecological integrity of the whole northern landscape. It will require building an understanding of ecosystem flows and processes across multiple scales, both within and beyond traditional use areas, and how those systems may be altered by human activity and natural forces like climate change.

This principle applies urgently and particularly to this region, at this time, because of its unique character and the changes that are predicted for it. There is clear scientific evidence that the ecosystems of the Far North will be subjected to a magnitude and rate of climate change that exceeds historic levels, and that they may be pushed beyond their natural, dynamic states. Current approaches to land use and landscape change will not be adequate to achieve the objectives for the Far North as expressed in the proposed *Far North Act*.

New development in the Far North must be approached cautiously, and planned and managed such that it does not itself exacerbate the magnitude and intensity of climate change, while still promoting community well-being. Management strategies must be designed to adjust in response to new knowledge. Hence, land use designations must reflect the need to maintain ecological processes, retain overall landscape connectivity, conserve native biodiversity and sustain social and ecological resilience.

Many specific recommendations follow as a consequence of the matters discussed in Chapters 2 through 4. We have focussed and grouped them in a way we believe supports an ambitious but achievable vision for the Far North that can be shared by all residents of Ontario and beyond.

1. CREATE A COORDINATED GOVERNMENT-WIDE STRATEGY FOR THE MANAGEMENT OF INTERIM AND ONGOING DEVELOPMENT

In the short time the *Far North Science Advisory Panel* has been convening, development interest in the Far North has dramatically heightened and numerous commitments and agreements are already moving ahead in the absence of formal land use planning. At the same time, global climate change, mobility and technology are accelerating the predicted trajectories of environmental and social change in the region. The Panel is deeply concerned about the potential for inadequately controlled development to compromise ecological integrity in the region, and thus the ability of communities and governments to achieve the objectives of the draft Far North legislation. In particular, we note that unplanned development can result in inadvertent and irreversible environmental deficits, and erode the region's ecological resilience in the face of rapid change.

This report highlights the imperative for careful planning and management of development intensity and extent across the region as a whole. The Panel believes that this approach is necessary to protect ecological integrity and resilience while delivering social and economic benefits to the region. However, existing approval mechanisms, including traditional environmental assessment, are geared to the approval of individual projects, not landscape-wide development. Indeed, existing structures and processes may act as disincentives to working across ministerial, jurisdictional, and community boundaries towards comprehensive landscape management.

Because permissions for individual development projects are being granted now, the Panel recommends the immediate creation of a coordinated government-wide strategy, aimed at minimizing the adverse ecological impacts of interim development as community planning proceeds. Project- or activity-specific approvals will fail to capture the cumulative impacts of development on ecological integrity over the region and over time (see Recommendation 3.1 below).

2. IMMEDIATELY DESIGNATE THE 'RING OF FIRE' AS A PRIORITY MANAGEMENT AREA WITH AN INTERIM SUB-REGIONAL PLANNING PROCESS

While pressure for development is increasing across the Far North, nowhere is it more intense than in the Ring of Fire, where recent mineral discoveries have focused international exploration and development interest. More than 90% of active claims in the Far North are in this area and along two potential access and power transmission corridors toward the south. Planning for full-scale mine development is occurring far in advance of any community land use planning processes or the development of the Far North Land Use Strategy. Traditional use areas of at least five communities lie within the Ring of Fire, but all downstream communities will be affected by management decisions taken there.

The Panel stresses that access routes and development activities must be planned from a broader regional perspective (see subsequent recommendations). The Ring of Fire and associated access corridors occupy at least 10% of the total land area of the Far North. Poorly planned access routes and transmission lines in particular have the potential to fragment habitat and create irreversible impacts on terrestrial and aquatic systems, including species abundance and distribution, carbon storage, and contamination of wild foods. The Panel therefore recommends that the Ring of Fire be immediately recognized as a Priority Management Area where a coordinated, government-wide sub-regional land use strategy should be developed as soon as possible. This interim planning process would bring together all affected First Nations communities and relevant Ministries, and would incorporate the principles and approaches set out in the following recommendations intended for the Far North as a whole.

3. IMMEDIATELY ESTABLISH THE FAR NORTH LAND USE STRATEGY

The following recommendations contain the Panel's advice on the necessary components of a Far North Land Use Strategy. Pursuant to Recommendation 1, the strategy must include government-wide policies, including those for project approvals, as well as details about approaches for data collection and management.

3.1 CONDUCT LAND USE PLANNING TO PROTECT ECOLOGICAL INTEGRITY OF THE REGION AS A WHOLE, WHILE ALSO ACHIEVING SOCIO-ECONOMIC OBJECTIVES

In the vast and largely intact ecosystems of the Far North, there is an imperative to consider the potential for human impacts on entire ecological landscapes, connected by large-scale flows of water, materials, and organisms. Conventional approaches to land use planning are inadequate and will not serve well in this region. They have been designed for landscapes that are already greatly altered from their original condition, where the goal is to protect the "best of what is left" for conservation purposes. In the Far North, this approach must be reversed to consider "how much is too much?" – how much development can be supported, and how can it be implemented such that the natural and cultural values and ecological integrity of the region are not compromised by such activities?

The Panel strongly recommends an approach to management of the Far North that considers comprehensive and integrated planning and management of the entire landscape. This can be accomplished by having an overarching Far North Land Use Strategy in place in a timely fashion that identifies the criteria for: 1) a system of large representative core protected areas[5*], 2) additional site-specific protected areas to conserve and/or connect significant and unique features, 3) active management areas for economic development, and 4) the intervening lands that provide a supportive conservation "matrix" within which the other elements are embedded. These four categories should work together to ensure native biodiversity is conserved, landscape-level connectivity is maintained, and that ecological processes operate to support the integrity and resilience of this globally unique region. Together, they provide a means of bringing together multiple community based land use plans into a coherent whole, as envisioned in the draft *Far North Act*.

3.2 MITIGATE CLIMATE CHANGE BY PREVENTING OR MINIMIZING THE LOSS OF CARBON STORAGE IN BIOMASS AND SOIL

This report has demonstrated the global importance of stored carbon in the Far North. Steps must be immediately taken to protect these stores, including ensuring (1) no loss or minimal loss of the carbon stored in the living biomass and soil of forests and peatlands of the region; (2) recognition of the global uniqueness and significance of carbon storage on the Hudson Bay and James Bay Lowland; and (3) recognition of the importance of carbon stored in intact old growth forests.

[5*] *Protected areas are clearly defined geographical spaces, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values. In the Far North, protected areas should be designated through community based land use planning, and should be areas where industrial development (mines, hydro-power, forestry, and other energy development) and associated road networks are prohibited, with other uses to be determined, managed, and monitored by communities.*

A greenhouse gas neutral strategy should be an explicit goal of Far North land use planning and land use management at all scales. Assessment of land use change must include a 'cost' for the net loss of carbon function of the landscape and, as noted previously, the Far North Land Use Strategy and community plans should designate conservation areas where the densest carbon pools exist, paying special attention to the stores and active carbon-sequestration of the peatlands of the region. Consideration should be given to putting value on these carbon stores in ways that enable communities to benefit from their stewardship of them.

In view of the important regional and global role these carbon stores play, it is important that the full greenhouse gas function and the physical climate services, not just carbon stores and sequestration, are accounted for in land use changes that affect peatlands and forests.

Finally, the Panel emphasizes that land use plans should not rely on the restoration of wetlands and peatlands as the means of mitigating environmental impacts of land use, as this is unlikely to restore their full carbon functions.

3.3 CONSIDER THE IMPACTS OF CLIMATE CHANGE IN LAND USE PLANNING

The projections of climate change described in this report carry the potential of many and considerable impacts on the communities of the Far North. Impacts will vary depending on the latitude and geographic location of the community and will have important implications for infrastructure and resource development, including roads and infrastructure corridors and mining operations. It is therefore critical that such development should only proceed after the potential impacts of climate change have been taken into account in the planning process. Given the implications of climate change for First Nations communities it is essential that community land use plans incorporate an assessment of climate change impacts and strategies for enhancing the climate change resilience of the community.

3.4 ESTABLISH A FRAMEWORK FOR PROTECTING AREAS OF CULTURAL AND ECOLOGICAL SIGNIFICANCE

For conservation planning to be inclusive of the wide range of Far North values, the network of protected areas should include, at a minimum:

- Areas of cultural and community value;
- Large core areas representative of the full range and proportional occurrence of regional ecological variation, including landform, geology, ecological systems, and disturbance regimes, that can serve as benchmarks against which to evaluate change in surrounding landscapes, and are of sufficient size (greater than 2 million ha) to accommodate natural disturbance regimes;
- Additional areas of ecological significance (e.g., ecosystems and landforms of conservation interest, high biodiversity areas, key habitat for focal species and species at risk, wildlife migration or breeding aggregation sites);
- Areas important for the maintenance of viable populations of area-demanding species (e.g., migratory species and anadromous fish moving from salt to fresh water to spawn), ecological systems and processes;
- Areas where it is possible to conserve both biodiversity and carbon, including the highest-

productivity forests, wetlands and peatlands in the Far North; for example, forested areas along the southern perimeter of the region and in more isolated situations northward, and peatlands and coastal, estuarine and riparian wetlands of the Hudson Bay Lowland.

Traditional harvest should be considered as part of the normal activities in all land use designations for the Far North, including protected areas. This recognition is consistent with protected areas elsewhere in Canada and internationally. Traditional harvest should be regularly monitored by communities, with conservation measures to be applied consistent with an adaptive management process (see below).

3.5 USE WATERSHEDS OR OTHER NATURAL BOUNDARIES AS THE BASIS FOR ESTABLISHING PROTECTED AREAS

Wherever possible, core representative benchmark areas must correspond in their extent to the boundaries of entire watersheds or sub-watersheds, or other natural units, to reflect the higher level of ecological integrity of such natural landscape units, and to prevent or mitigate deleterious downstream impacts from development. In unprotected watersheds, headwaters should receive priority for protection.

Water provides essential connectivity and ecological services in this region, including drinking water for all First Nations communities. Clean drinking water is so integrally linked to the quality of the land that it can be considered a "product" of a healthy watershed. Water, and the need for water planning on a watershed basis, should therefore be recognized and respected in all community based land use plans, and in the Far North Land Use Strategy itself.

Effective watershed planning for the Far North should include attention to the provision of habitat, carbon storage and sequestration, and the presence and potential for mobilization of contaminants. Source water protection must be the guiding principle that protects local community water sources and shapes effective land use planning for the protection of downstream communities and ecosystems.

Water modeling should include scenarios that reflect the changes that may arise from climate change and development, including flooding, declining water levels, rising coastlines, and the compounding effects of key stressors.

3.6 COORDINATE PLANNING AND MANAGEMENT ACROSS ADMINISTRATIVE BOUNDARIES

Effective landscape-wide conservation planning of the type recommended in this report will require cooperation across political and management boundaries. These include, but are not limited to, the southern legal limit of the Far North, First Nations' community planning area boundaries, neighbouring jurisdictions, and provincial and federal lands.

Strategies required to address the needs of far-ranging species, maintain aquatic connectivity, and accommodate ecosystem dynamics such as wildfire exceed the scale of individual traditional-use areas in the region and hence cross the boundaries of community based land use plans. As a result, landscape-scale planning, including cross-boundary, cross-discipline, and cross-agency cooperation, will be essential.

Similarly, such considerations also require cross-boundary planning with adjacent provinces and other management authorities, including responsible agencies in Manitoba, Québec and in the Federal Government. Planning that affects terrestrial-marine interfaces in the James Bay and Hudson Bay region, and internationally-recognized sites such as Ramsar Convention-designated wetlands, Important Bird Areas, and continental flyways, necessitates additional coordination.

4. PLAN DEVELOPMENT INCREMENTALLY, IN A CONSIDERED, PROACTIVE FASHION

4.1 ASSESS AND MANAGE CUMULATIVE IMPACTS

Achieving whole-landscape conservation requires a comprehensive management system, including a process to manage cumulative effects, which is largely impossible within the context of traditional project-specific piecemeal planning. Development across the Far North must be carefully planned, implemented incrementally, monitored over time, and adapted as necessary based on new information regarding the response of the natural systems to development activities. The management system should identify potential thresholds of ecological impact, based on the best available science and traditional knowledge. To achieve this, areas of intensive development (active management areas) should occupy only a small proportion of the total land area of the Far North.

4.2 MAINTAIN THE EXISTING MORATORIUM ON LARGE-SCALE HYDRO-ELECTRIC DEVELOPMENT AND EXTEND IT TO INCLUDE INTER-BASIN WATER DIVERSIONS

The moratorium on large-scale hydro-electric development enforced by the Northern Rivers Commitment already recognizes that large-scale hydro-electric development has the potential to irretrievably alter the wetlands and river systems on which the ecosystems as well as the communities of the Far North depend. Moreover, the current project-based environmental assessment process is inadequate to address the cumulative and broad-scale impacts of such development. The mobilization of mercury and its accumulation in fish and fish consumers, the impacts on fish migration, the movement of invasive species, and alterations to the carbon storage capacity of peatlands are some of the processes that are affected by the hydrology in the watersheds of the large rivers. If any large-scale alteration of any major river in the Far North is contemplated, then comprehensive cumulative effects research will be required for the appropriate duration to adequately assess the consequences of the proposed development. Until such time as this work has been completed and the results evaluated, the existing moratorium should remain in place. No new hydrological project designed to divert water between drainage basins should occur.

It would be appropriate and in keeping with this recommendation if smaller-scale run-of-the-river hydro-electric generation were to be examined as an energy source for communities in the Far North as a means of improving community health and well-being through elimination of reliance on diesel.

4.3 PLAN TRANSPORTATION AND TRANSMISSION CORRIDORS IN A COORDINATED FASHION, RECOGNIZING COMMUNITY NEEDS AND PROTECTING SIGNIFICANT ECOLOGICAL FEATURES

Development in the Far North, including mineral exploration activities, depends on access. Efforts to provide this access are already underway, through numerous but uncoordinated private and local agreements and initiatives, for example for the development of local airstrips. The Panel therefore believes that there is a pressing need for a proactive comprehensive access-management plan dealing with all modes of transportation and transmission, as an explicit component of the Far North Land Use Strategy.

Highest priority should be given to improving access to and among communities rather than for individual development projects, and planning must respect the significance and character of the entire Far North (for example, the limitations of road-building materials in some areas and the enormous number of waterbodies that require crossing structures).

A comprehensive access plan at a regional scale should establish limits on road densities and on water-access and wetland incursion in advance of development, rather than relying on after-the-fact mitigation and decommissioning. Design standards should be developed that minimize risks to ecological integrity. Most importantly, the access-management plan must recognize and minimize cumulative effects from unplanned environmental and social impacts of new roads.

4.4 PREVENT THE INTRODUCTION OF INVASIVE SPECIES

To date, ecosystem integrity and function across the Far North have been remarkably uncompromised by invasive species and non-native pests and pathogens. This dominance of native biota can only be maintained through careful vigilance and deliberate actions that restrict inadvertent importation of invasive species. Access networks and their use must be closely monitored, and equipment should be inspected and cleaned to reduce the risk of accidental importation. Rehabilitation projects should use only native species. Exclusion of invasive species should be a goal of the Far North access-management plan (see previous recommendation). Even the simple introduction of baitfish or other live bait such as earthworms can have significant ecosystem consequences.

5. APPLY THE BEST CONTINUOUS LEARNING APPROACHES THROUGH ADAPTIVE MANAGEMENT

5.1 BASE MANAGEMENT DECISIONS ON THE BEST AVAILABLE KNOWLEDGE, BUT REGULARLY REVISIT AND REVISE STRATEGIES AS THE KNOWLEDGE BASE IMPROVES

The future of the Far North holds great uncertainty, both because of natural forces such as climate change and fire, and because of the potential for human activity to alter ecological systems. Available data for Far North ecosystems are scanty and often dated. Effective land use planning will ensure that the knowledge base improves over time, and that management strategies adapt as understanding develops. Furthermore, it is essential to measure and manage the cumulative effects of many activities across the Far North's vast landscape. We recommend the adoption of adaptive management as a framework for this, whereby policy choices, probable management outcomes, and key uncertainties are identified and evaluated in advance with best available evidence, with decisions treated as experiments to be adapted on the basis of documented outcomes.

Given the magnitude of change and the uncertainties about the rate and magnitude of change in the physical and biological landscapes, the overall planning process needs to be an open learning process, with careful and incremental introduction of development in the region, and a clear emphasis on avoiding undesirable outcomes. Ecosystem conditions must be evaluated regularly. Management strategies must be adjusted as new information becomes available and the impacts of land use change and climate change on ecosystems and the physical landscape become evident. This will require a flexible policy framework and a commitment to the comprehensive long-term monitoring program that will be essential to support an adaptive management approach.

An adaptive management approach also means that development interests must be able to demonstrate ecological sustainability as a guiding principle, and as a condition for approval, and must be prepared to adjust operational regimes as their impacts on the region become apparent. It also requires transparency and a public understanding that management approaches will change as time goes on and direct experience with outcomes of development is accumulated in the Far North.

5.2 SUPPORT PLANNING AND MANAGEMENT WITH AN APPROPRIATE DECISION-SUPPORT SYSTEM

As stressed repeatedly in this report, the Far North's ecological systems are complex and naturally variable. Climate change and human activity will bring new pressures to bear on them, with outcomes that cannot be predicted with certainty. The Panel believes that effective land use planning will require the development of a decision-support system that allows planners to integrate and evaluate available information and test "what if?" scenarios. This system should incorporate tools for the evaluation of phenomena that vary over time and space, to support the assessment of policy and management options, both locally and across the region. It should allow planning within, among and between the scales of individual community based land use plans, and would allow the systematic evaluation of strategic issues and alternatives associated with establishment of the Far North Land Use Strategy. Decision-support systems of this type rely on a number of quantitative and qualitative computer simulation models and associated software platforms. The assumptions, structure and parameters on which such models are based should to be open, public, and transparent. The models should be useable by both broad scale and community based planners and open to external review.

Collectively, the models, tools and broader decision-support system should provide the means by which issues such as interconnectedness can be evaluated, and should permit the testing of alternative land use designations. Such a decision-support system must include the ability to explicitly consider the uncertainties associated with both natural dynamics and anthropogenic change. Various scenarios of the future need to be part of these modelling tools. Efforts should be made to encourage the development of appropriate and useful models to assess changes in ecological integrity and function in a changing climate.

6. PROVIDE COMMUNITIES AND GOVERNMENTS WITH THE NECESSARY INFORMATION RESOURCES FOR PLANNING AND MANAGEMENT

6.1 CREATE A FAR NORTH INFORMATION SYSTEM TO FACILITATE THE USE OF BEST AVAILABLE KNOWLEDGE, INCLUDING ABORIGINAL TRADITIONAL KNOWLEDGE

Land use strategies and plans must be based on the best available scientific and aboriginal traditional information. In the Far North, information resources are spatially incomplete at best, leaving gaps where no information is available. This stands in stark contrast to the information resources that are available to land use planning and resource management elsewhere in Ontario. The Panel acknowledges the considerable efforts of the Ontario Ministry of Natural Resources to compile and augment available information for the Far North through their four-year Far North Information and Knowledge Management Plan. However, the Panel observes that effective community based land use planning will require data and information from other agencies and sources, which must be fully and easily available to communities and to the public.

The draft *Far North Act* gives significant planning responsibility to communities that cannot presently access the kinds of information routinely available to southern Ontario residents. The Panel believes that land use planning in the Far North therefore demands the development of a permanent, centralized information repository – a Far North Information System – for region-wide information and data that can be shared by all interested parties, including on-line remote access and use. The System would be the information hub for the Far North Land Use Strategy and a support centre for community based land use planning. It should serve as a means to facilitate access to existing data sets and knowledge sources, and translate and deliver them to various users in a culturally and linguistically appropriate manner.

Dedicated financial support for such an Information System is necessary to sustain long-term monitoring and data management, and community support. It is obvious to the Panel that planning in the Far North will rely on traditional knowledge and science. It is our hope that the Far North Information System will provide a means of making both forms of information available to the planning process.

In addition to supporting communities in their planning efforts, the Panel believes that a Far North Information System would be a powerful mechanism to bring land managers and researchers together, facilitating interactions and supporting collaborative research on Far North ecosystems.

The Panel further notes that an adaptive management approach to land use planning in the Far North will require not only ongoing monitoring, but periodic independent expert review of the Far North strategy land use plans, emerging information, and adjustment of management strategies. Inevitably, this process will raise important scientific questions and require science advice. The System could provide a hub for such advice on an ongoing basis.

6.2 IMPROVE THE AVAILABLE INFORMATION BASE THROUGH A COMPREHENSIVE INVENTORY, ENHANCED MONITORING, AND SPECIAL STUDIES

The Panel recommends that a comprehensive biophysical inventory program, incorporating both scientific and aboriginal traditional knowledge, be completed for the Far North as an essential first step in developing any information management system. The inventory program should provide baseline information from the establishment of long-term, securely funded monitoring programs.

The monitoring program should formally report to the Legislature on the "State of the Far North" every 5 years. The report should include a detailed assessment of ecological integrity and human health. The Panel recommends that a broad approach be adopted in coordination with other ministries, other governments and researchers.

The volume of data generated by these efforts will require an effective information management system that ensures data and information quality, and timely access and storage as recommended above (6.1).The Panel recognizes that the Ontario Government (through the Ministry of Natural Resources and the Ministry of Northern Development, Mines, and Forestry) has launched a renewed focus on northern inventory, monitoring and science. This is a commendable step in the right direction, but the current investment is not sufficient. We recommend that the program receive additional resources so a comprehensive inventory can be completed within 5 years (see Appendix B).

Land use planning decisions must be based on the best available scientific and traditional information, and useable information to support land use planning is required quickly, a point well illustrated by the current pressures for resource development in the Ring of Fire. Proper evaluation of potential impacts of development will also require baseline information.

The Panel notes the high standard set by the draft Far North Act requirement with respect to maintenance of carbon storage and sequestration. To that end, we emphasize the need for documentation of ecosystem-based carbon storage and sequestration in the Far North, including area, depth and carbon density in upland ecosystems (soils, above ground biomass) and peatlands. Information is also needed on local and sub-regional areas of high wind, solar, and run-of-the-river hydro potential to validate present coarse-scale regional assessments.

In particular, the Panel recommends that a comprehensive study be conducted to determine the current concentration of mercury in fish in the Far North, as well as its sources and sinks, and the pathways though which it enters the food chain. In essence the study should provide a total and methyl mercury mass balance for selected wetlands of the Far North. It should include a food consumption study and should determine the likely effects of climate change on processes occurring in wetlands. The results of the study should be used as the basis for a monitoring program and must be taken into account before any reservoir construction occurs in the Far North (see Recommendation 4.2).

An initial list of information and monitoring needs is provided in Appendix B.

Appendix A: Panel Terms of Reference

Far North Science Advisory Panel
Terms of Reference
January 19, 2009

Purpose:

- To provide the best scientific and technical advice to the Minister of Natural Resources on how to achieve the government's vision for the Far North.

Functions:

The Far North Science Advisory Panel will:

- Provide scientific knowledge and advice with regard to the identification, discussion of policy approaches and options to the Minister of Natural Resources, the Nishnawbe Aski Nation, and Far North First Nations as they develop a Land Use Planning Framework for the Far North which will inform the drafting of Far North planning legislation.
- Provide advice on the status of, and current or emerging threats to, the natural resources, wildlife and ecology of the Far North.
- Identify science-based issues and questions relevant to land use planning decisions in the Far North.
- Provide advice on the state and availability of scientific knowledge to address the above issues and questions
- Respond to requests for science advice from the Far North Advisory Council, the Minister and Nishnawbe Aski Nation.

Areas of Interest:

The Panel will address and consider a broad range of issues and interests related to Far North planning, including (but not limited to):

- areas of protection
- terrestrial and aquatic ecosystems, biodiversity, mineral resources, carbon, permafrost, climate change
- resource development practices including mining, renewable energy, forestry
- land-use planning
- Improving understanding of human caused and environmental disturbance(s) in the biodiversity and natural resources of the Far North and possible protective and adaptive strategies

Membership:

- The Panel will include individuals from outside and inside government with recognized scientific expertise in disciplines that reflect the areas of interest outlined above

- Panel members are not to send substitutes when they are unable to attend meetings
- The Panel will be chaired by a non-governmental scientist

Term and Meetings:

- The Science Advisory Panel will be established in the fall of 2008 and remain in place for up to 10 months (i.e. September 2009), at which time the need for additional meetings will be assessed.
- The Panel will also review science needs associated with the development of the broad-scale land use strategy for the Far North region and make recommendations on how to meet these science needs.
- The Panel will meet as frequently as required to support the government and the Far North Advisory Council (approximately once every 4 to 6 weeks).
- In addition to regular meetings, the Panel may also form task teams to provide analysis of specific issues.
- Early meetings will focus on supporting the proposed Far North Planning Framework.
- Meetings will be based in Toronto, with the option to connect by teleconference when the agenda permits.

Reporting:

- On behalf of the Far North Science Panel, the Chair will report to the Minister of Natural Resources through the office of the Assistant Deputy Minister, Far North.
- Summaries of Panel discussions will be maintained including a written summary of the key advice provided by panel members. The summaries are not to be circulated beyond panel members.
- A final report will be prepared by the Facilitator with input and review by the Science Panel members and submitted to the Minister.
- The Panel may choose to develop an Interim Report(s), which will also be submitted to the Minister.

Confidentiality:

- Panel members may receive confidential information and material (e.g. presentation material) and will be expected to keep such materials confidential.

Support:

- Far North Branch, Ministry of Natural Resources will provide secretariat support.
- Panel meetings will be supported by a facilitator
- On request, MNR may reimburse Panel members for reasonable travel expenses, at the prevailing Ontario Government rates. Non Government panel members will be reimbursed for time spent at panel meetings at a rate of 300.00 per day.

Appendix B: List of Inventory and Monitoring Needs

Land-use planning at the level normally applied across Ontario is complex and expensive, and founded on the availability of high-quality information and the expertise of professional land-use planners, which supports communities in their planning requirements. Such a norm can be achieved across the Far North if there is a concerted commitment to new administrative arrangement and to investments in information and in planning capacity. Strong long-term financial support is a fundamental requirement of such planning. The Ontario Ministry of Natural Resources has been identified as the lead agency in this regard, providing one-window support, and coordinating the support of other provincial agencies.

The Far North of Ontario offers a unique global opportunity for cooperation, sharing and mutual support between and among governments and government agencies, educational institutions and corporations, in support of a globally exemplary, proactive planning and development regime, one that meets First Nation expectations while meeting provincial, national and global responsibilities for conservation of nature and its many ecological services.

Core information resources are recommended as basic elements of the Far North Land Use Strategy and of community land-use plans. The following are listed in the order of the objectives in the draft Far North Act (6 (1-4), 7(4)a-c). Such information is available from, or under development, or developable, by public agencies and others, including the Ontario Ministries of Natural Resources (lead), Aboriginal Affairs, Environment, Culture, Northern Development, Mines and Forestry, and Infrastructure and Energy; as well as federal agencies such as Environment Canada and Indian and Northern Affairs; and First Nations.

1. First Nations

a. Guidelines on policy, science and technical matters, supporting land-use planning and resource management.

b. Traditional ecological and cultural knowledge – environmental, social and economic values, resources, traditions and expectations

c. General information

- Fine-scale community and region-wide infrastructure mapping and databases
- Population, employment and housing statistics and projections
- Land-use, leases, licenses, staking, claims, water sources, discharge points, etc.
- Research camps; meteorological, hydrological and wetland stations, stream gauges
- Water-quality and wild-food contaminant data (fish, traditional wild foods, potable water, etc.)

2. Areas of cultural values, and areas of ecological values

a. Cultural values – areas of traditional, historical and current land use and resource use; Ontario Ministry of Culture (Archaeology and Heritage Planning Unit) archaeological database; pre-development investigations of heritage values

b. Ecological values – areas of traditional knowledge of site-specific ecological values; areas of otherwise identified natural-heritage significance; current protected areas, areas of natural and scientific interest (life science and earth science), important bird areas, wildlife/waterfowl sanctuaries, etc.; up-to-date topographic mapping and satellite imagery; watershed mapping (at all scales); land-cover (ecological system) classification and mapping.

3. Biological diversity, and ecological processes and functions, including the storage and sequestration of carbon

a. Biological diversity – areas of traditional, historical and current use of fish and wildlife species

- Fish – distribution, presence and concentrations, by traditional and modern survey methods; documentation of wild food needs; commercial and recreational fishery potential; fishing camps, fixed and fly-in; invasive aquatics
- Wildlife – distribution, presence and concentrations, by traditional and modern survey methods; critical areas for breeding, rearing and migration, for waterfowl and shorebird areas (geese, ducks, moose, etc.); migratory corridors and flyway and staging areas;
- Species and ecosystems of conservation concern and Species at Risk (e.g., caribou, polar bear, wolverine, sturgeon; anadromous trout, whitefish and char; marine mammals; regulated Species at Risk; species of conservation concern (S1-3), and of restricted Far North ranges; ecosystems of conservation concern (peatlands, permafrost, tundra, coastal and estuarine marshes, disjunct northern forest, etc.)
- Ecological processes and functions - surface lake and river waters, wetlands, peatlands, and permafrost peatlands; permafrost terrain and features (continuous and discontinuous); wildfires (distribution, history, predictions) and fire protection zoning; contaminant flows, and contaminant indices for water, fish and wild meat; aquatic connectivity within watersheds; estuarine interactions; areas of maximum adaptive capacity for climate change.
- Storage and sequestration of carbon – areas of concentrated carbon storage and sequestration (forest, peatland, permafrost, total)

4. Areas of natural-resource values, and sustainable economic development

a. Forest Resource Inventory – forest-type mapping, fibre volumes, regeneration potential; ecoregion-specific growth-yield rates; current aerial photography, orthography, LiDar imagery

b. Mineral Potential – areas of potential for mineral occurrence; areas of aggregate potential

c. Energy potential – occurrences of community-based and of export-based hydro-electric potential (in-stream river-run, dam-based, peaking dams); occurrences of community-based and export-based wind and solar operations

d. Community well-being indices – measured indices of community well-being, contaminant inventories, wild-food surveys, traditional community values.

Endnotes

[1] Ontario Ministry of Natural Resources. 1984. Water Quantity Resources of Ontario. OMNR, Toronto.

[2] http://atlas.nrcan.gc.ca/site/english/maps/climatechange/atmospherestress_greenhousegasemissionbygas

[3] Amiro, B.D., Todd, J.B., Wotton, B.M., Logan, K.A., Flannigan, M.D., Stocks, B.J., Mason, J.A., Martell, D.L., and Hirsch, K.G. 2001. Direct carbon emissions from Canadian forest fires, 1959–1999. Can. J. For. Res. 31: 512–525. These authors report 27 Mt/yr of carbon from an average annual burned area of 2 million ha for Canada. Ontario contributes an average of 10% of the national burned area, or 2.7 Mt/yr of carbon. This is equal to 9.9 Mt/yr of CO2e.

[4] Compare Ontario's two atlases of breeding birds. M.Obbard, OMNR, pers. comm.; also see Gunn, J. and Snucins, E. 2010. Brook charr mortalities during extreme temperature events in the Sutton River, Hudson Bay Lowlands, Canada. Hydrobiologia DOI 10.1007/s10750-010-0201-3 (published online).

[5] In the 1960s, flint arrowheads, bone awls and lances were found near Fort Albany and, in the 1970s, chert spear points and pottery shards were found at a rivermouth near Cape Henrietta Maria. In 1974, studies at the Cape and Hawley Lake found caribou hunting sites with chert points and hearth charcoal that dated from 915 AD. A survey of the Severn River in the 1980s recovered caribou bones that were harvested at river crossings by mass capture techniques, such as a fence or snares. In 1988 evidence was found on the Shamattawa River of fish weirs that had been in full-time use both before and after European contact. Occupation of the higher ground of the Canadian Shield was even earlier; in 2005, human bones found along Big Trout Lake were dated, before reburial, at 5000 years old. Traditional practice at the time of European contact was the seasonal movement of families and clans to harvest the caribou, fish and fowl that were their staples, and to actively take advantage of many other resources, and of shelter and trade. Fort Albany, W. Kenyon; elsewhere on the coast, K. Dawson; Cape Henrietta Maria and Hawley Lake, J. Pollock and W. Noble; Severn River, J.-L. Pilon; Shamattawa, K. Lister; Big Trout Lake, S. Hamilton. Lister, K.R. 1988. Provisioned at fishing stations: fish and the native occupation of the Hudson Bay Lowland. Pp. 72-99, in, C.S. Reid (ed.) Boreal Forest and Sub-Arctic Archaeology. Occas. Publ. of the Ontario Archaeological Association 6. Pilon, J.-L. 1987. Washahoe Inninou Dahtsuounoaou: Ecological and Cultural Adaptation Along the Severn River in the Hudson Bay Lowlands of Ontario. Ontario Ministry of Citizenship and Culture, Conservation Archaeology Report 10. http://anthropology.lakeheadu.ca/projects/bigtroutlake/ Lytwyn, V.P. 2002. Muskekowuck Athinuwick. Original People of the Great Swampy Land. University of Manitoba Press, Winnipeg.

[6] Prickett, A. 1811. A Larger Discourse of the Same Voyage, and the Success Thereof. New-York Historical Society, I.Riley Publishers. The "partridges" were ptarmigan.

[7] James, T. 1973. The Dangerous Voyage of Captain Thomas James. Coles Publishing Ltd., Toronto.

[8] Pierre Radisson held a higher opinion of the region. In 1659 he canoed the shores of Lake Superior and learned about Hudson Bay. His dream was a fur trade based on Hudson Bay, and he took his dream to England for support. In 1668 he sailed for Hudson Bay and built a fort at the bottom of James Bay.

The Nonsuch returned to England the next spring loaded with fur and a royal charter followed in 1670. To the new Hudson's Bay Company went "the sole trade and commerce…together with all the lands." The Far North became the first part of North America west of the Atlantic to have permanent European settlement. The native Cree fed, fueled and otherwise sustained the Company's coastal posts, some of which have been continuous communities ever since. The first of the Company's posts in the interior of North America was also in the Far North, near the forks of the Albany and Kenogami rivers.

[9] In the 1730s, the Company directed its men to study the natural history of the region. Alexander Light, for example, sent home specimens of Golden Eagle, Spruce Grouse, Snowy Owl, Willow Ptarmigan, Northern Hawk Owl, Gyrfalcon and Porcupine. A live wolverine was sent. James Isham followed and he shipped at least fifteen other new North American birds, including the Great Blue Heron, Snow Goose, Whooping Crane, Tundra Swan and Sandhill Crane. See: Houston, S., T. Ball and M. Houston. 2003. Eighteenth-Century Naturalists of Hudson Bay. McGill-Queen's University Press, Montreal & Kingston. Rich, E.E. 1949. James Isham's Observations on Hudsons Bay, 1743. The Champlain Society, Toronto. Rich, E.E. 1954. Moose Fort Journals 1783-85. The Hudson's Bay Record Society, London.

[10] Coats, W. 1852. The Geography of Hudson's Bay. (Ed. J. Barrow) The Hakluyt Society. Lytwyn, Victor. 2002. Muskekowuck Athinuwick: Original People of the Great Swampy Land. (Winnipeg: University of Manitoba Press, 2002), xiv 289 pp.

[11] Lytwyn, Victor. 2002. Muskekowuck Athinuwick: Original People of the Great Swampy Land. (Winnipeg: University of Manitoba Press, 2002), xiv 289 pp.

[12] Innis, H.A. 1956, rev. ed. The Fur Trade in Canada. University of Toronto Press, Toronto.

[13] Schooling, W. 1920. The Hudson's Bay Company 1670–1920. HBC, London. Map.

[14] Dean, W.G. (ed.) 1969. Economic Atlas of Ontario. University of Toronto Press, Toronto.

[15] McIlraith, S.J. and Stott, G.M. 2005. Lowlands drill hole data compilation; Ontario Geological Survey, Miscellaneous Release Data 152.

[16] Percival, J.A., Sanborn-Barrie M., Skulski T., Stott G.M., Haelmstedt H., and White D.J. (2006). Tectonic Evolution of the Western Superior Province from NATMAP and Lithoproble Studies. Canadian Journal of Earth Sciences 43 (7), 1085-1117.

[17] Ontario Geological Survey, (2000). Bedrock Geology, seamless coverage of the Province of Ontario. Ontario Geological Survey, ERLIS Data Set 14.

[18] Barnett, P.J., (1992). Quaternary geology of Ontario, p. 1011-1088. In P.C. Thurston, H.R. Williams, R.H. Sutcliffe, and G.M. Stott, ed., Geology of Ontario. Ontario Geological Survey, Sudbury, Special Volume 4, part 2, 1525 pp.

[19] Dyke, A.S., Morris, T.F., and Green, D.E.C. (1991) Postglacial tectonic and sea level history of the central Canadian Arctic. Geological Survey of Canada Bulletin 397, 56pp

[20] Through the early 1990s (Rouse, W.R. 1991. Impacts of Hudson Bay on the terrestrial climate of the Hudson Bay Lowlands. Arctic and Alpine Research 23:24-30. Fig. 2B), and on a continuing basis (Gagnon A.S. and W.A. Gough. 2005a. Trends and variability in the dates of ice freeze-up and break-up over Hudson Bay and James Bay. Arctic, 58, 370–382. Gagnon A.S. and W.A. Gough. 2005b. Climate change scenarios for the Hudson Bay region: an intermodel comparison. *Climate Change*, 69, 269–297

[21] Bryson, R.A. 1966. Air masses, streamlines and the boreal forest. *Geographical Bulletin* 8:228-269.

[22] Rouse, W.R. 1991. Impacts of Hudson Bay on the terrestrial climate of the Hudson Bay Lowlands. *Arctic and Alpine Research* 23:24-30

[23] Canada Surveys and Mapping Branch. 1974. The national atlas of Canada. 4th ed. Ottawa, Macmillan Co., in association with Dept. of Energy, Mines and Resources, and Information Canada. Canada Environment Canada. 1981. Canadian Climate Normals 1951-80. Dept. of Energy, Mines and Resources, Ottawa.

[24] Riley, J. L., 2003. Flora of the Hudson Bay Lowland and its postglacial origins. NRC Press, Ottawa, Ontario, 236 pp.

[25] Riley, J. L., 2003. Flora of the Hudson Bay Lowland and its postglacial origins. NRC Press, Ottawa, Ontario, 236 pp.

[26] Meyer J.L., Strayer D.L., Wallace J.B., Eggert S.L., Helfman G.S. & Leonard N.E. (2007). The contribution of headwater streams to biodiversity in river networks. *Journal of the American Water Resources Association*, 43, 86-103.

[27] Pringle C.M. (2001). Hydrologic connectivity and the management of biological reserves: A global perspective. *Ecological Applications*, 11, 981-998.

[28] Gomi T., Sidle R.C. & Richardson J.S. (2002). Understanding processes and downstream linkages of headwater systems. *Bioscience*, 52, 905-916.

[29] Gomi T., Sidle R.C. & Richardson J.S. (2002). Understanding processes and downstream linkages of headwater systems. *Bioscience*, 52, 905-916.

[30] Meyer J.L., Strayer D.L., Wallace J.B., Eggert S.L., Helfman G.S. & Leonard N.E. (2007). The contribution of headwater streams to biodiversity in river networks. *Journal of the American Water Resources Association*, 43, 86-103.

[31] Pringle C.M. (2001). Hydrologic connectivity and the management of biological reserves: A global perspective. *Ecological Applications*, 11, 981-998.

[32] Warren M.L. Jr. & Pardew M.G. (1998). Road crossings as barriers to small-stream fish movement. Transactions of the American Fisheries Society 127, 637-644.

[33] The major rivers of the region contribute about 3.5% of Canada's total river flow (Albany 967 m3/sec; Moose 780 m3/sec; Severn 714 m3/sec; Winisk 474 m3/sec; Attawapiskat 279 m3/sec; and Ekwan 98 m3/sec). Royal Commission on the Northern Environment. 1985. North of 50: an Atlas of Far Northern Ontario. University of Toronto, Dept. of Geography. 119 pp.; Ontario Ministry of Natural Resources. 1984. Water Quantity Resources of Ontario. OMNR publ. 5932, Toronto, Ontario. 71 pp.; Cox 1978. Counts and Measurements of Ontario Lakes. Ontario Ministry of Natural Resources Report. 114pp.

[34] Cox, E. T. 1978. Counts and Measurements of Ontario Lakes. Ontario Ministry of Natural Resources. Toronto, Ontario, Canada.

[35] Ontario Ministry of Natural Resources. 1984. Water Quantity Resources of Ontario. OMNR publ. 5932, Toronto, Ontario. 71 pp.

[36] OMNR Water Resource Atlas, 2009. http://www.lio.ontario.ca/imf-ows/imf.jsp?site=waterpower_en; Ontario Hydro. 1991. Providing the Balance of Power. Ontario Hydro (Toronto). Ontario Power Generation. 2006. Ontario's Integrated Power System Plan. Toronto. Browne, D.R. 2007. Freshwater Fish in Ontario's Boreal. WCS Canada. 100pp.

[37] "Highly deficient of gauging stations"; Mishra, A.K. and P. Coulibaly. 2009. Hydrometric network evaluation for Canadian watersheds. Journal of Hydrology 380: 420-437.

[38] Roy, A. C. 1979. Northern Ontario Water Resources Studies: The Water Quality of Selected Lakes in the Arctic Watershed of Ontario. OMOE NE Region Report, Toronto, Ont. 95 p.

[39] Canada. Ministry of Indian Affairs and Northern Development. 2006. Report of the Expert Panel on Safe Drinking Water
for First Nations. Ministry of Public Works and Government Services Canada. 77pp.

[40] O'Driscoll, N.J., A.N. Rencz and D.R.S. Lean. 2005. Mercury Cycling in a Wetland Dominated Ecosystem: A multidisciplinary study: Kejimkujik Park, Nova Scotia. SETAC Press, Pensacola FL, 391 pp. St. Louis, VL; Rudd, JWM; Kelly, CA; Beaty, KG; Bloom, NS; Flett, RJ .(1994). Importance of wetlands as sources of methyl mercury to boreal forest ecosystems. CAN. J. FISH. AQUAT. SCI. Vol. 51, no. 5, pp. 1065-1076. Watras, C. J., Morrison, K. A., Kent, A., Price, N., Regnell, O., Eckley, C., et al. (2005). Sources of methylmercury to a wetland-dominated lake in northern Wisconsin. Environmental Science and Technology, 39(13), 4747-4758.

[41] The unpublished Albany River study was done by the Mushkegowuk Environmental Research Centre and found concentrations of mercury ranging from 0.3 ug/g to 1.6 ug/g for pike and 0.4ug/g to 3ug/g for walleye. These levels are very high compared to the consumption guideline of 0.5 ug/g.

[42] http://www.arcticnet.ulaval.ca

[43] N. Roulet, pers. comm., 2009.

[44] Gorham E 1991 Northern peatlands: Role in the carbon budget and probable responses to global

warming. Ecological Applications 1 182-195. Also see: Canadian Water Resources Journal. *Peatlands Special Issue: Improving Hydrological Prediction in Canadian Peatland.* Vol. 34 (4), Winter 2009.

[45] Tarnocai C, Canadell JG, Schuur EAG, Kuhry P, Mazhitova G, and Zimov S 2009 Soil organic carbon pools in the northern circumpolar permafrost region. Global Biogeochem Cycles 23

[46] Gorham E, Janssens J, and Glaser P 2003 Rates of peat accumulation during the postglacial period in 32 sites from Alaska to Newfoundland, with special emphasis on northern Minnesota. *Canadian Journal of Botany* 81 429-438

[47] Peatland is terrain in which there is more than 30 to 40cm accumulation of organic matter.

[48] Peat depths: bogs north, mean 1.82m±0.56 (n=33); Bogs south, mean 2.55m±0.79 (n=124). Peat plateau, mean 3.61m±0.8 (n=3). Fens north, mean 1.37m±0.73 (n=31); fens south, mean 2.15m±1.11 (n=76). Unpublished data, J.L.Riley.

[49] Table 1 (section 2) provides summary statistics on physical and biological characteristics. For review, see Sims, R.A., J.L. Riley and J.K. Jeglum. 1979. Vegetation, flora and vegetational ecology of the Hudson Bay Lowland: a literature review and annotated bibliography. Can. For. Serv., Sault Ste. Marie. Report 0-X-297. 177pp.

[50] Denman K, Brasseur G, and others 2007 Couplings Between Changes in the Climate System and Biogeochemistry. In: Solomon S, Qin D, Manning M, Marquis M, Averyt K, Tignor M, Miller JH and Chen Z eds *Climate Change 2007 zThe Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge 499-587

[51] N. Roulet, pers. comm. 2009. A gigatonne, Gt, is equal to 1015 g or 100,000,000 tonnes, and is equivalent to 1 Pg, the other mass term commonly used in assessments of global carbon cycles. In greenhouse gas studies the masses can be express in either the mass of the entire molecule – e.g. CO2 = 44 g, CH4 = 16 g, or the mass of carbon contained in the molecule, e.g. CO2 = 12 g CO2-C, CH4 = 12 g CH4-C. In this section the masses refer to the mass of C in the molecule. To convert from CO2 and CH4 to mass of C multiple by 12/44 and 12/16, respectively.

[52] P. Gray, OMNR, pers. comm., 2009.

[53] Frolking S, and Roulet NT 2007 Holocene radiative forcing impact of northern peatland carbon accumulation and methane emissions. *Global Change Biology* 13 doi: 10.1111/j.1365-2486.2006.01339.

[54] Roulet, N. et al. 1994. role of the Hudson Bay Lowland as a source of atmospheric methane. Journal of Geophysical Research 99: 1439-1454.

[55] Maxwell, B. 1992. Arctic climate: potential for change under global warming. In F.S. Chapin, R.L. Jeffries, J.F. Reynolds, G.R. Shaver and J. Svoboda eds. Arctic ecosystems in a changing climate. Academic Presss, pp. 11-34.

[56] J. Riley, pers. comm., 2009

[57] Compare, for example, Tarnocai, C. 2006. The effect of climate change on carbon in Canadian peatlands. Global and Planetary Change 53(4):222-232. And, Dorrepaal, E. et al. 2009. Carb on respiration from subsurface peat accelerated by climate arming in the subarctic. Nature 460:616-619. And, Laine, J. et al. 1996. Effect of water-level drawdown on global climate warming: northern peatlands. Ambio 25(3):179.

[58] The Canadian Fire Weather Index (FWI) measures the relative (qualitative) effect of fuel moisture and wind on fire potential in a standard forest-fuel type (such as jack pine).

[59] Turetsky, pers. comm., 2009

[60] Sigler, J.M., Lee X., Munger, W. 2003. Emission and long-range transport of gaseous mercury from a large-scale Canadian boreal forest fire. Environ. Sci. Technol. 1;37(19):4343-7.

[61] Turetsky, M. R., J. W. Harden, H. R. Friedli, M. D. Flannigan, N. Payne, J. Crock, and L. F. Radke (2006), Wildfires threaten mercury stocks in northern soils, Geophys. Res. Lett., 33, L16403, doi:10.1029/2005GL025595.

[62] "Latitudinal gradient," see pp.14-18, Figures. 5-8, Riley 2003. "Above-ground biomass," see National Forest Inventory (2001, table 4, p.33, Hudson Plain Ecozone Status and Trends Assessment, draft 2009 07 03).

[63] For forest distribution, see Table 1, above; OMNR Provincial Land Cover (2000); and D. de Launay, pers. comm., 2009, for estimate of 6-7%.

[64] "Forest landscape" is used here to include the peatland ecosystems that characterize such boreal landscapes worldwide, and particularly in the Far North.

[65] For example, Ter-Mikaelian MT, Colombo SJ, Chen JX. 2008. Fact and fantasy about forest carbon. Forestry Chronicle 84:166-171. Ferguson C, Nelson EA, Sherman GG. 2008. Turning Up the Heat: Global Warming and the Degradation of Canada's Boreal Forest. Greenpeace Canada, 55 pp.

[66] Bonan GB (2008) Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *Science* 320: 1444-1449

[67] Covington WW (1981) Changes in forest floor organic-matter and nutrient content following clear cutting in northern Hardwoods. *Ecology* 62, 41-48. Peltoniemi M, Makipaa R, Liski J, Tamminen P (2004) Changes in soil carbon with stand age - an evaluation of a modelling method with empirical data. Global Change Biology 10, 2078-2091. Fitzsimmons MJ, Pennock DJ, Thorpe J (2004) Effects of deforestation on ecosystem carbon densities in central Saskatchewan, Canada. Forest Ecology and Management 188, 349-361. And, Johnson DW, Curtis PS. 2001. Effects of forest management on soil C and N storage: meta analysis. Forest Ecology and Management 140: 227-238.

[68] There is a strong theoretical basis for predicting soil carbon losses as a result of soil warming that favours increased decomposition; see for example Bonan GB, Pollard D, Thompson SL (1992) Effects of boreal forest vegetation on global climate. *Nature* 359, 716-718. Direct measurements of soil carbon flux indicate that young regenerating forests generally do show substantial carbon losses; see Bala G, Caldeira K, Wickett M, Phillips TJ, Lobell DB, Delire C, Mirin A (2007) Combined climate and carbon-cycle effects of large-scale deforestation. *Proceedings of the National Academy of Sciences* 104, 6550-6555. Boreal forests may require decades to recover a positive carbon balance following harvest.

[69] Ni WG, Woodcock CE (2000) Effect of canopy structure and the presence of snow on the albedo of boreal conifer forests. **Journal of Geophysical Research-Atmospheres** 105, 11879-11888. Davidson A, Wang SS (2005) Spatiotemporal variations in land surface albedo across Canada from MODIS observations. *Canadian Journal of Remote Sensing* 31, 377-390. Amiro et al. 2006)

[70] Bala et al. 2007, Bonan 2008, Spracklen DV, Bonn B, Karslaw KS. 2008. Boreal forests, aerosols and the impacts on clouds and climate. Phil. Trans. R. Soc. A 366: 4613-4626. Ullah S, Frasier R, Pelletier L, Moore TR. (2009) Greenhouse gas fluxes from boreal forest soils during the snow-free period in Quebec, Canada. Canadian Journal of Forest Research 39: 666-680. Spracklen, D.V., Bonn, B., Carslaw, K.S. (2008), Boreal Forests, Aerosols and the Impacts on Clouds and Climate, Philosophical Transactions of the Royal Society A, 366:4613-26.

[71] The data from 1980-1994 were taken from the Canadian Large Fire Database as provided by MNR. For the years 1995-2007 the data were mapped using remote sensing as provided by Natural Resources Canada. In both cases a water-mask was used to remove water bodies from the calculation of burned area.

[72] Wotton B.M. and Flannigan, M.D. (1993). Length of the fire season in a changing climate. Forestry Chronicle, 69, 187-192.

[73] Kneeshaw, D. and S. Gauthier. 2003. Old growth in the boreal forest: A dynamic perspective at the stand and landscape level. Environ. Rev. 11(S1): S99–S114.

[74] Environment Canada. 2010. Hudson Plains Ecozone Status and Trends Assessment. In preparation.

[75] Dobbyn, J.S. 1994. Atlas of the Mammals of Ontario. Federation of Ontario Naturalists, Toronto. And NHIC List of Ontario Mammals.; NHIC List of Ontario Mammals

[76] Obbard, M.E. T. L. McDonald, E. J. Howe, E. V. Regehr, and E. S. Richardson. 2007. Polar Bear Population Status in Southern Hudson Bay, Canada. U.S. Geological Survey Administrative Report U.S. Department of the Interior, Reston, VA. 36 pages.

[77] Obbard, M.E. T. L. McDonald, E. J. Howe, E. V. Regehr, and E. S. Richardson. 2007. Polar Bear Population Status in Southern Hudson Bay, Canada. U.S. Geological Survey Administrative Report U.S. Department of the Interior, Reston, VA. 36 pages.

[78] Ontario's Woodland Caribou Conservation Plan. August 2009.Ministry of Natural Resources. 21 p.

[79] Ahti, T. and R.L. Hepburn. 1967. Preliminary studies on Woodland Caribou range, especially on lichen stands in Ontario. Ontario Dept. Of Lands and Forests, Research Report (Wildlife) 74.

[80] Compare de Vos, A., and R. L. Peterson. 1951. A review of the status of woodland caribou (Rangifer caribou) in Ontario. Journal of Mammalogy 32: 329–337; Cringan, A.T. 1957. History, food habits and range requirements of the woodland caribou of continental North America. Trans. North Am. Wildl. Conf. 22: 485-501;Simkin, D.W. 1965. A preliminary report of the woodland caribou study in Ontario. Ont. Dept. of Lands and Forests, Wildl. Sect. Rep. No. 59, Toronto. 76 p.; Darby, W.R., H.R. Timmermann, J.B. Snider, K.F. Abraham, R.A. Stefanski and C.A. Johnson. 1989. Woodland caribou in Ontario: background to a policy. Ont. Min. Of Nat. Resour., Wildlife Branch. 38 p.; Cumming, H.G. 1998. Status of woodland caribou in Ontario: 1996. Rangifer, Spec. Iss. 10: 99-104.

[81] Cumming, H.G. 1998. Status of woodland caribou in Ontario: 1996. Rangifer, Spec. Issue 10: 99-104.

[82] OMNR Unpublished data; K.F.Abraham, pers. comm.

[83] Compare current numbers with estimates by Cumming, H.G. 1998. Status of woodland caribou in Ontario: 1996. Rangifer, Spec. Iss. 10: 99-104. Also see: Abraham, K.F., and J.E. Thompson. 1998. Defining the Pen Islands caribou herd of southern Hudson Bay. *Rangifer* (10):33-40.

[84] Abraham, K.F. and R.L. Jefferies. 1997. High goose populations: causes, impacts and implications. In B.D.J. Batt, ed., Arctic ecosystems in peril. Arctic Goose Habitat Working Group, Joint Venture Publication. USFWS, Washington and CWS, Ottawa, pp. 7-72; Kotonen, P.M. and R.L. Jefferies. 1997. Long-term destruction of wetland vegetation by Lesser Snow Geese. Ecoscience 4: 1895-1898.

[85] Bird Studies Canada. Importance of Canada's Boreal Forest to Landbirds. Canadian Boreal Initiative

[86] Chu, Cindy, Charles K. Minns, and Nicholas E. Mandrak. 2003. Comparative regional assessment of factors impacting freshwater fish biodiversity in Canada. Can. J. Fish. Aquat. Sci. 60(5): 624–634.

[87] Wilson, C.C. and P.D.N Hebert. 1996. Phylogenic origins of lake trout (*Salvelinus namaycush*) in eastern North America. Canadian Journal of Fisheries and Aquatic Sciences 53:2764-2775.
Wilson, C.C. and P.D.N Hebert. 1998. Phylogeography and postglacial dispersal of lake trout (*Salvelinus namaycush*) in North America. Canadian Journal of Fisheries and Aquatic Sciences 55:1010-1024.

[88] Kaufman, S., E. Snucins, J.M. Gunn and W. Selinger. 2009. Impacts of road access on lake trout (*Salvelinus namaycush*) populations: regional scale effects of overexploitation and the introduction of smallmouth bass (*Micropterus dolomieu*). Can. J. Fish. Aquat. Sci. 66(2): 212-223

[89] Malette, M.D. 1993. Growth and anadromy of brook trout (Salvelinus fontinalis (Mitchell)) from Sutton River, Hudson Bay Lowland. M.Sc. Thesis. Biology Department, Laurentian University, Sudbury, ON. Steele, P.O. 1986. Life history strategies of a north temperate salmonid, Salvelinus fontinalis, in Polar Bear Provincial Park, Ontario. Ph.D. Thesis. Faculty of Graduate Studies, University of Western Ontario, London, ON.

[90] Threader, R.W. and C.S. Brosseau. 1986. Biology and management of the lake sturgeon in the Moose River, Ontario. North American Journal of Fisheries Management. 6:383-390.

[91] Lake Sturgeon in Ontario. OMNR, July 2009.

[92] Berkes, F., A. Hughes, P.J. George, R.J. Preston, B.D. Cummins and J.Turner. 1995. The persistence of aboriginal land use: fish and wildlife harvest areas in the Hudson and James Bay Lowland, Ontario. Arctic 48: 81-93. Dewailly, E., C. Blanchet, S. Gingras, S. Lemieux and B.J. Holub. 2002. Cardiovascular disease risk factors and n-3 fatty acid status in the adult population of James Bay Cree. American Journal of Clinical Nutrition 76(1) 85-92.

[93] Kaufman, S., E. Snucins, J.M. Gunn and W. Selinger. 2009. Impacts of road access on lake trout (*Salvelinus namaycush*) populations: regional scale effects of overexploitation and the introduction of smallmouth bass (*Micropterus dolomieu*). Can. J. Fish. Aquat. Sci. 66(2): 212-223

[94] Gunn, J. and Snucins, E. 2010. Brook charr mortalities during extreme temperature events in the Sutton River, Hudson Bay Lowlands, Canada. Hydrobiologia DOI 10.1007/s10750-010-0201-3 (published online).

[95] Riley, J.L. 2003. Flora of the Hudson Bay Lowland and its Postglacial Origins. NRC Research Press Monograph. 236pp.

[96] Colombo S, McKenney D, Lawrence K, and Gray P 2007 Climate Change Projections for Ontario: Practical Information for Policymakes and Planners. Applied Research and Development Branch, Ontario Ministry of Natural Resources, Sault Ste. Marie, Ontario 38 pp.

[97] Flato GM, Boer GJ, Lee WG, McFarlane NA, Ramsden D, Reader MC, and Weaver. AJ 2000 The Canadian Centre for Climate Modeling and Analysis Global Coupled Model and its Climate. Climate Dynamics 16 451-467.

[98] Nakicenovic N, Alcamo J, Davis G, de Vries B, Fenhann J, Gaffin S, Gregory K, Grübler A, Jung T, Kram T, La Rovere E, Michaelis L, Mori S, Morita T, Pepper W, H P, Price L, Riah K, Roehrl A, Rogner H-H, Sankovski A, Schlesinger M, Shukla P, Smith S, Swart R, van Rooijen S, Victor N, and Dadi Z 2000 Special Report on Emissions Scenarios. Intergovernmental Panel on Climate Change, Cambridge, England 599.

[99] Solomon S, Qin D, Manning M, Z. C, Marquis M, Averyt KB, Tignor M, and Miller HL 2007 Climate Change 2007: The Physical Science Basis. Intergovernmental Panel on Climate Change, Cambridge, England 996 pp. The ensemble analysis is completed for the mid 21st century (2050) and the results are reported as mean anomalies for the period of 2041 – 2070 from the simulated reference climate of 1961-1990. This corresponds to the second time interval reported by Colombo et al. The spatial resolution of output for the ensemble analysis is 2.5 x 2.5 degrees and approximately 18 grid cells cover the Far North Region. In both the Colombo et al. and CIARD analyses the results are reported as climate anomalies relative to a simulated reference climate. Both sets of analyses report the changes in temperature and precipitation only. Climate models are continuously developing and the projections from climate models

are constantly being updated. The global scale results have not changed substantially over the 20 years of scientific assessments by the IPCC but the regional results have changed significantly. Most of the climate models in the AR4 assessment are coupled atmosphere-ocean models with some representation of land surface processes. The models vary in complexity and the components of the climate system they contain. Several areas of development in climate models are particularly relevant to the Far North but are not included in the present assessment; they include sea ice and permafrost dynamics, and coupled ocean and terrestrial carbon cycles. Some climate models now contain as prognostic variables these three components, but most do not.

[100] Friedlingstein P, Cox P, Betts R, Bopp L, Von Bloh W, Brovkin V, Cadule P, Doney S, Eby M, Fung I, Balal G, John J, Jones C, Joss F, Kato T, Kawamika M, Knoor W, Lindsay K, Matthews H, Raddatz T, Rayner P, Reick C, Roeckner E, Sschnitzler K-G, Schnurr R, Strassmann K, Weaver A, Yoshikawa C, and Zeng N 2006 Climate–Carbon Cycle Feedback Analysis: Results from the C4MIP Model Intercomparison. Journal of Climate 19 3337-3353

[101] Lawrence D, and Slater A 2005 A projection of severe near-surface permafrost degradation during the 21st century. Geophysical Research Letters 32 Art. No. L24401; Lawrence DM, Slater AG, Romanovsky VE, and Nicolsky DJ 2008 Sensitivity of a model projection of near-surface permafrost degradation to soil column depth and representation of soil organic matter. Journal of Geophysical Research F: Earth Surface 113 .

[102] Lawrence DM, Slater AG, Tomas RA, Holland MM, and Deser C 2008 Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss. Geophys Res Lett 35

[103] Raupach MR, Marland G, Ciais P, Le Quere C, Canadell JG, Klepper G, and Field CB 2007 Global and regional drivers of accelerating CO2 emissions. Proceedings of the National Academy of Sciences of the United States of America 104 10288-10293. See also website of the Global Carbon Project for most reent estimates of anthropogenic emissions (http://www.globalcarbonproject.org/).

[104] Dyck MG, Soon W, Baydack RK, Legates DR, Baliunas S, Ball TF, and Hancock LO 2008 Reply to response to Dyck et al. (2007) on polar bears and climate change in western Hudson Bay by Stirling et al. (2008). *Ecological Complexity* 5 289-302; Dyck MG, Soon W, Baydack RK, Legates DR, Baliunas S, Ball TF, and Hancock LO 2007 Polar bears of western Hudson Bay and climate change: Are warming spring air temperatures the "ultimate" survival control factor? Ecological Complexity 4 73-84; Stirling I, Derocher AE, Gough WA, and Rode K 2008 Response to Dyck et al. (2007) on polar bears and climate change in western Hudson Bay. Ecological Complexity 5 193-201; Stirling I, and Parkinson CL 2006 Possible effects of climate warming on selected populations of polar bears (Ursus maritimus) in the Canadian Arctic. Arctic 59 261-275

[105] Monson, Bruce A. 2009. Trend Reversal of Mercury Concentrations in Piscivorous Fish from Minnesota Lakes: 1982−2006. Environ. Sci. Technol. 43 (6), pp 1750–1755. Carrie, J., F. Wang, H. Sanei, R. W. Macdonald, P. M. Outridge and G. A. Stern. Increasing Contaminant Burdens in an Arctic Fish, Burbot (*Lota lota*), in a Warming Climate. Environ. Sci. Technol., 2010, 44 (1), pp 316–322. Publication Date (Web): December 3, 2009.

[106] Frolking S, Roulet NT, Moore TR, Lafleur PM, Bubier JL, and Crill PM 2002 Modeling the seasonal and annual carbon balance of Mer Bleue bog, Ontario, Canada. Global Biogeochemical Cycles 16 10.1029/2001GB001457; Frolking S, Roulet NT, Moore TR, Richard PJH, Pavoie M, and Muller SD 2001 Modeling Northern Peatland Decomposition and Peat Accumulation. Ecosystem 4 479-498; St-Hilaire F, Wu J, Roulet NT, Frolking S, Lafleur PM, Humphreys ER, and Arora V 2008 McGill Wetland Model: evaluation of a peatland carbon simulator developed for global assessments. Biogeosciences Discuss 5 1-37; Wania R, Ross I, and Prentice IC 2009 Integrating peatlands and permafrost into a dynamic global vegetation model: 1. Evaluation and sensitivity of physical land surface processes. Global Biogeochem Cycles 23; Wania R, Ross I, and Prentice IC 2009 Integrating peatlands and permafrost into a dynamic global vegetation model: 2. Evaluation and sensitivity of vegetation and carbon cycle processes. Global Biogeochem Cycles 23; Walter BP, Heimann M, and Matthews E 2001 Modeling modern methane emissions from natural wetlands 1. Model description. Journal of Geophysical Research - Atmospheres 106 34189-34206, 34110.31029/32001JD900165; Walter BP, Heimann M, and Matthews E 2001 Modeling modern methane emissions from natural wetlands. 2. Interannual variations 1982-1993. Journal of Geophysical Research 106 34207-34220,

[107] Wu J 2009 Simulating northern peatland-atmosphere carbon dioxide exchange with changes in climate. PhD Dissertation, Geography, McGill University.

[108] Friedlingstein P, Cox P, Betts R, Bopp L, Von Bloh W, Brovkin V, Cadule P, Doney S, Eby M, Fung I, Balal G, John J, Jones C, Joss F, Kato T, Kawamika M, Knoor W, Lindsay K, Matthews H, Raddatz T, Rayner P, Reick C, Roeckner E, Sschnitzler K-G, Schnurr R, Strassmann K, Weaver A, Yoshikawa C, and Zeng N 2006 Climate–Carbon Cycle Feedback Analysis: Results from the C4MIP Model Intercomparison. Journal of Climate 19 3337-3353.

[109] Ontario Greenhouse Gas Emissions Targets: A Technical Brief Monday, June 18, 2007 (*http://www.ene.gov.on.ca/publications/6793e.pdf*)

[110] Christensen TR, Johansson TM, Akerman HJ, Mastepanov M, Malmer N, Friborg T, Crill P, and Svensson BH 2004 Thawing sub-arctic permafrost: Effects on vegetation and methane emissions. Geophysical Research Letters 31 doi:10.1029/2003GL018680.

[111] Belyea LR, and Baird AJ 2006 Beyond "the limits to peat bog growth": cross-scale feedback in peatland development. Ecological Monographs 76 299-322; Hilbert DW, Roulet NT, and Moore TR 2000 Modelling and analysis of peatlands as dynamical systems. Journal of Ecology 88 230-242

[112] Christensen TR, Johansson TM, Akerman HJ, Mastepanov M, Malmer N, Friborg T, Crill P, and Svensson BH 2004 Thawing sub-arctic permafrost: Effects on vegetation and methane emissions. *Geophysical Research Letters* 31 doi:10.1029/2003GL018680; and Malmer N, Johansson T, and Christensen TR 2005 Vegetation, climate changes, and net carbon sequestration in a Northern-Scandinavian subarctic mire over 30 years. *Global Change Biology* 11 1895-1109.

[113] Briffa KR, Jones PD, Schweingruber FH, Shiyatov SG, Cook ER (1995) Unusual twentieth-century summer warmth in a 1,000-year temperature record from Siberia. *Nature* 376, 156. Briffa KR, Schweingruber FH, Jones PD, Osborn TJ, Shiyatov SG, Vaganov EA (1998) Reduced sensitivity of recent

tree-growth to temperature at high northern latitudes. Nature 391, 678-682. Jacoby GC, D'Arrigo RD, Davaajamts T (1996) Mongolian tree rings and 20th century warming. *Science* 273, 771.

[114] Barber VA, Juday GP, Finney BP (2000) Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. *Nature* 405, 668-673. Wilmking M, Juday GP, Barber VA, Zald HSJ (2004) Recent climate warming forces contrasting growth responses of white spruce at treeline in Alaska through temperature thresholds. Global Change Biology 10, 1724-1736. Wilmking M, Juday GP (2005) Longitudinal variation of radial growth at Alaska's northern treeline - recent changes and possible scenarios for the 21st century. *Global and Planetary Change* 47, 282-300.

[115] D'Arrigo RD, Kaufmann RK, Davi N, Jacoby GC, Laskowski C, Myneni RB, Cherubini P (2004) Thresholds for warming-induced growth decline at elevational tree line in the Yukon Territory, Canada. *Global Biogeochemical Cycles* 18. Comparable figures not available for northern Ontario.

[116] Vaganov EA, Hughes MK, Kirdyanov AV, Schweingruber FH, Silkin PP (1999) Influence of snowfall and melt timing on tree growth in subarctic Eurasia. *Nature* 400, 149-151. Goetz SJ, Bunn AG, Fiske GJ, Houghton RA (2005) Satellite-observed photosynthetic trends across boreal North America associated with climate and fire disturbance. *Proceedings of the National Academy of Sciences of the United States of America* 102, 13521-13525.

[117] Cannell MGR, Smith RI (1986) Climatic warming, spring budburst and frost damage on trees. *Journal of Applied Ecology* 23, 177-191. Hogg EH, Brandt, James P, Kochtubajda B (2002) Growth and dieback of aspen forests in northwestern Alberta, Canada, in relation to climate and insects. Canadian Journal of Forest Research 32, 823. Hanninen H, Kolari P, Hari P (2005) Seasonal development of Scots pine under climatic warming: effects on photosynthetic production. *Canadian Journal of Forest Research* 35, 2092-2099. Hanninen H (2006). Climate warming and the risk of frost damage to boreal forest trees: Identification of critical ecophysiological traits. *Tree Physiology* 26:889-898.

[118] Barber VA, Juday GP, Finney BP (2000) Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. *Nature* 405, 668-673. Hogg EH, Brandt, James P, Kochtubajda B (2002) Growth and dieback of aspen forests in northwestern Alberta, Canada, in relation to climate and insects. Canadian Journal of Forest Research 32, 823. Wilmking M, Juday GP (2005) Longitudinal variation of radial growth at Alaska's northern treeline - recent changes and possible scenarios for the 21st century. *Global and Planetary Change* 47, 282-300.

[119] Stewart RB, Wheaton E, Spittlehouse DL (1998). Climate change: implications for the boreal forest. In: *Emerging air issues for the 21st century: The need for multidisciplinary management.* Proceedings. Speciality conference, Sep. 22–24, 1997, Calgary. AB. Legge AH, Jones LL (eds.). Air and Waste Management Assoc., Pittsburg, PA, pp 86-10. Chapin FS, McGuire AD, Randerson J, Pielke R, Baldocchi D, Hobbie SE, Roulet N, Eugster W, Kasischke E, Rastetter EB, Zimov SA, Running SW (2000) Arctic and boreal ecosystems of western North America as components of the climate system. *Global Change Biology* 6, 211-223.; Podur JJ, Martell DL, Knight K (2002) Statistical quality control analysis of forest fire activity in Canada. *Canadian Journal of Forest Research* 32,195-205. Flannigan MD, Logan KA, Amiro BD, Skinner WR, Stocks BJ (2005) Future area burned in Canada. *Climatic Change* 72, 1-16. Goetz SJ, Bunn AG, Fiske GJ, Houghton RA (2005) Satellite-observed photosynthetic trends across boreal North

America associated with climate and fire disturbance. *Proceedings of the National Academy of Sciences of the United States of America* 102, 13521-13525.

[120] Stewart RB, Wheaton E, Spittlehouse DL (1998). Climate change: implications for the boreal forest. In: *Emerging air issues for the 21st century: The need for multidisciplinary management. Proceedings.* Speciality conference, Sep. 22–24, 1997, Calgary. Volney WJA, Fleming RA (2000) Climate change and impacts of boreal forest insects. *Agriculture Ecosystems and Environment* 82: 283-294. Hogg EH, Brandt, James P, Kochtubajda B (2002) Growth and dieback of aspen forests in northwestern Alberta, Canada, in relation to climate and insects. Canadian Journal of Forest Research 32, 823

[121] Malcolm JR, Puric-Mladenovic D, Shi H (2005) Projected tree distributions, tree migration rates, and forest types in Ontario under a 2°C global temperature rise. Pp. 52-99 In: Implications of a 2°C global temperature rise for Canada's natural resources (T Tin, ed.). WWF-World Wide Fund For Nature, Gland, Switzerland.

[122] Way DA, Sage RF (2008) Elevated growth temperatures reduce the carbon gain of black spruce [Picea mariana (Mill.) BSP]. *Global Change Biology* 14, 624-636.

[123] Hogg EH, Bernier PY (2005) Climate change impacts on drought-prone forests in western Canada. *Forestry Chronicle* 81, 675-682.

[124] Davidson A, Wang SS (2005). Spatiotemporal variations in land surface albedo across Canada from MODIS observations. Canadian Journal of Remote Sensing 31, 377-390. Amiro BD, Barr AG, Black TA, Iwashita H, Kljun N, McCaughey JH, Morgenstern K, Murayama S, Nesic Z, Orchansky AL, Saigusa N (2006). Carbon, energy and water fluxes at mature and disturbed forest sites, Saskatchewan, Canada. Agricultural and Forest Meteorology 136, 237-251.

[125] Wilmking, M., J. Harden, and K. Tape (2006), Effect of tree line advance on carbon storage in NW Alaska, J. Geophys. Res., 111.

[126] Wilmking, M., J. Harden, and K. Tape (2006), Effect of tree line advance on carbon storage in NW Alaska, J. Geophys. Res., 111.

[127] Betts RA (2000) Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. *Nature* 408, 187-190. Callaghan TV, Bjorn LO, Chernov Y, Chapin T, Christensen TR, Huntley B, Ims RA, Johansson M, Jolly D, Jonasson S, Matveyeva N, Panikov N, Oechel W, Shaver G, Schaphoff S, Sitch S (2004) Effects of changes in climate on landscape and regional processes, and feedbacks to the climate system. *Ambio* 33, 459-468.

[128] Wilmking, M., J. Harden, and K. Tape (2006), Effect of tree line advance on carbon storage in NW Alaska, J. Geophys. Res., 111.

[129] OMNR ecoregions 3S, 3W, 3E.

[130] Amiro, B.D., B.J. Stocks, M.E. Alexander, M.D. Flannigan, and B.M. Wotton. (2001). Fire, climate change, carbon and fuel management in the Canadian boreal forest. International Journal of Wildland Fire

10: 405-413.

[131] Wotton, B.M.; Martell, D.M.; Logan, K.A.(2003). Climate change and people-caused forest fire occurrence in Ontario. Climatic Change, 60, 275-295.

[132] Flannigan, M.D., Logan, K.A., Amiro, B.D., Skinner, W.R. and Stocks, B.J. (2005). Future area burned in Canada. Climatic Change. 72:1-16.

[133] Price C, and Rind D, (1994) The impact of a 2×CO2 Climate on lightning-caused fires. Journal of Clmate, 7, 1484–1494.

[134] Westerling, A.L, Hidalgo, H.G., Cayan, D.R., Swetnam, T.W. Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. (2006). Science 313 (5789), 940-943.

[135] http://www.powerauthority.on.ca/Storage/18/1362_Part_3-6_Hydroelectricity_in_Ontario.pdf (accessed April 8, 2010).

[136] OMNR 2007. Waterpower Site Release and Development Review. PL 4.10.05 (May 21, 2007).

[137] Drinkwater, Kenneth and T. Frank. 1994. Effects of river regulation and diversion on marine fish and invertebrates. Aquatic Conservation: Marine and Freshwater Ecosystems 4(2): 135-151.

[138] Environment Canada. (Eds.) 2000. Ecological Assessment of the Boreal Ecozone.

[139] Environment Canada and Fisheries and Oceans Canada. 1992a. Federal Ecological Monitoring Program (FEMP) — Lake Winnipeg, Churchill–Nelson River System. Vol. 1.

[140] Bodaly, R.A., Hecky, R.E. and Fudge, J.P.: 1984, Can. J. Fish. Aquat. Sci. 41, 682. Environment Canada and Fisheries and Oceans Canada. 1992b. Federal Ecological Monitoring Program (FEMP) — Lake Winnipeg, Churchill–Nelson River System. Vol. 2.

[141] DesLandes, J.C., S. Guénette, Y. Prairie, D. Roy, R. Verdon, and R., Fortin. 1995. "Changes in Fish Populations Affected by the Construction of La Grande Complex (Phase I), James Bay Region, Quebec." Canadian Journal of Zoology 73 : 1, 860-77.

[142] Environment Canada. (Eds.) 2000. Ecological Assessment of the Boreal Ecozone.

[143] Kelly et al., 1997. Studies from a shallow reservoir in northwestern Ontario's Experimental Lakes Area have demonstrated that flooded wetlands had switched from being carbon sinks, sequestering carbon at a rate of 6.6 g/m^2 per year, to carbon sources, releasing 130 g/m^2 per year. Tremblay, A., L. Varfalvy, C. Roehm and M. Garneau. 2004. The issue of greenhouse gases from hydroelectric reservoirs: from boreal to tropical regions. In: Proceedings of the United Nations Symposium on Hydropower and Sustainable Development, Beijing, China, October 27-29, 2004. Studies from northern Québec that are representative of larger, deeper northern reservoirs show that the amount of greenhouse gases emitted from reservoirs varies over time. The maximum occurs in the first 3 to 5 years after impoundment and then the reservoir

emissions become similar to those of boreal lakes with the net loss of carbon function due to the loss of exchanges between the atmosphere and now-flooded terrestrial ecosystems.

[144] Environment Canada. (Eds.) 2000. Ecological Assessment of the Boreal Ecozone.

[145] Environment Canada. (Eds.) 2000. Ecological Assessment of the Boreal Ecozone.

[146] Schetagne. R. 1994. Water quality modification after impoundment of some large northern reservoirs. Archiv für Hydrobiologie, Special Issues 40: 223–229.

[147] Rosenberg, D M; Berkes, F; Bodaly, R A; Hecky, R E; Kelly, C A; Rudd, J WM. 1997. Large-scale impacts of hydroelectric development. Environmental Reviews Vol 5 pp. 27-54

[148] Beamesderfer, R.C.P., and R.A. Farr. 1997. Alternatives for the protection and restoration of sturgeons and their habitat. Env. Biol. Fish. 48: 407-417. Jager, H.I. 2006. Chutes and ladders and other games we play with rivers: I. upstream passage. Canadian Journal of Fisheries and Aquatic Sciences 63(1): 165-175.; Jager, H.I. 2006. Chutes and ladders and other games we play with rivers: II. translocation. Canadian Journal of Fisheries and Aquatic Sciences 63(1): 176-184.

[149] McKinney, M.L. 1997. Extinction vulnerability and selectivity: Combining ecological and paleontological views. Annu. Rev. Ecol. Syst. 28:495-516; Purvis, A., J.L. Gittleman, G. Cowlishaw, and G.M. Mace. 2000. Predicting extinction risk in declining species. P. Roy. Soc. Lond. B Bio. 267(1456):1947-1952.

[150] National Research Council Committee on Environmental Impacts of Wind Energy Projects. 2007. Environmental Impacts of Wind-Energy Projects. The National Academies Press, Washington, D.C. pp 394.

[151] Wallace P. Erickson, Gregory D. Johnson, and David P. Young Jr. 2005. A Summary and Comparison of Bird Mortality from Anthropogenic Causes with an Emphasis on Collisions. USDA Forest Service Gen. Tech. Rep. PSW-GTR-191.

[152] Winkleman, J.E. 1994. Bird/wind turbine investigations in Europe. Pp. 43-47 in: Proceedings of the National Avian-Wind Power Planning Meeting, Lakewood, Colorado. Prepared by LGL Ltd., Environmental Research Associates, King City, Ontario.

[153] Government of Ontario 2009. Proposed Growth Plan for Northern Ontario. Ontario Ministry of Energy and Infrastructure and Ontario Ministry of Northern Development, Mines, and Forestry. Toronto, ON. October 2009.

[154] Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V., and Woolmer, G. (2002). The human footprint and the last of the wild. Bioscience 52, 891-904.

[155] Gunn, J.M., and Sein, R. (2000). Effects of forestry roads on reproductive habitat and exploitation of lake trout (Salvelinus namaycush) in three experimental lakes. Canadian Journal of Fisheries and Aquatic Sciences 57, 97-104.

[156] Hunt, L.M., Lemelin, R.H., and Saunders, K.C. (2009). Managing Forest Road Access on Public Lands: A Conceptual Model of Conflict. Society & Natural Resources 22, 128-142.

[157] Thorne, J.H., Huber, P.R., Girvetz, E.H., Quinn, J., and McCoy, M.C. (2009). Integration of Regional Mitigation Assessment and Conservation Planning. Ecology and Society 14.

[158] Thorne, J.H., Huber, P.R., Girvetz, E.H., Quinn, J., and McCoy, M.C. (2009). Integration of Regional Mitigation Assessment and Conservation Planning. Ecology and Society 14.

[159] Fahrig, L., and Rytwinski, T. (2009). Effects of Roads on Animal Abundance: an Empirical Review and Synthesis. Ecology and Society 14.

[160] Fahrig, L., and Rytwinski, T. (2009). Effects of Roads on Animal Abundance: an Empirical Review and Synthesis. Ecology and Society 14. Forman, R.T.T., and Alexander, L.E. (1998). Roads and their major ecological effects. Annual Review of Ecology and Systematics 29, 207-231. Trombulak, S.C., and Frissell, C.A. (2000). Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14, 18-30.

[161] Government of Ontario 2009. Ontario Winter Roads program http://www.mndm.gov.on.ca/nordev/winter_roads_e.asp. Ontario Ministry of Northern Development, Mines and Forestry.

[162] Browne, D.R. 2007. Freshwater fish in Ontario's boreal: status, conservation and potential impact of development. Wildlife Conservation Society of Canada, Conservation Report 2, Toronto, Ontario, Canada.

[163] Kaufman, S.D., Snucins, E., Gunn, J.M., and Selinger, W. (2009). Impacts of road access on lake trout (Salvelinus namaycush) populations: regional scale effects of overexploitation and the introduction of smallmouth bass (Micropterus dolomieu). Canadian Journal of Fisheries and Aquatic Sciences 66, 212-223.

[164] Johnson, C.J., Boyce, M.S., Case, R.L., Cluff, H.D., Gau, R.J., Gunn, A., and Mulders, R. (2005). Cumulative effects of human developments on arctic wildlife. Wildlife Monographs, 1-36.

[165] Bevers, C. 2010. The history of Ontario's King's Highways. http://www.thekingshighway.ca/. Accessed March 30, 2010) .

[166] Hunt, L., G. D. Twynam, W. Haider, and D. Robinson. 2000. Examining the desirability for recreating in logged settings. Society & Natural Resources 13:717-734.

[167] Frair, J.L., Merrill, E.H., Beyer, H.L., and Morales, J.M. (2008). Thresholds in landscape connectivity and mortality risks in response to growing road networks. Journal of Applied Ecology 45, 1504-1513.

[168] Frair, J.L., Merrill, E.H., Beyer, H.L., and Morales, J.M. (2008). Thresholds in landscape connectivity and mortality risks in response to growing road networks. Journal of Applied Ecology 45, 1504-1513.

[169] Zhang and Barnes. 2007. Late Ordovician-Early Silurian conodont biostratigraphy and thermal maturity, Hudson Bay Basin. Bulletin of Canadian Petroleum Geology 55(3):179–216

[170] Procter, R.M., Taylor, G.C. and Wade, J.A. (1984). Oil and natural gas resources of Canada. Geological Survey of Canada, Paper 83-31, 59pp

[171] Almost 1600m of sedimentary rock were found offshore near the centre of Hudson Bay and 1200m near the coast, north west of Fort Severn. Re-examination of phosphatic microfossils from six selected drill holes showed that the burial of the rocks and their organic content had only resulted in slightly exceeding the lowest temperature (80°C – the lower limit of the "oil window") necessary for conversion of organic matter in the sediment to oil. See: Zhang, Dewing and Barnes, 2007

[172] Nicolas, M.P.B., and Lavoie, D. (2009). Hudson Bay and Foxe Basins Project: introduction to the Geo-mapping for Energy and Minerals, GEM-Energy initiative, northeastern Manitoba (parts of NTS 54) in Report of Activities 2009, Mantitoba Innovation, Energy and Mines, Manitoba Geological Survey, 160-164.

[173] Hamilton, S. M., A. K. Burt, K. H. Hattori, and J. Shirota, 2004, The distribution and source of forest ring-related methane in northeastern Ontario, in: Summary of field work and other activities: Ontario Geological Survey Open File Report 6145, 21-1–21-26.

[174] Provincial Recording Office, MNDM&F, personal communication, March 10, 2010.

[175] Provincial Recording Office, MNDM&F, personal communication, March, 2010.

[176] Sudbury Mining Solutions Journal v.6 (4), December 2009. For example, a number of Chinese-owned exploration companies have staked a large number of claims in the "Ring of Fire" after consulting with several First Nations.

[177] Stott, G.M. and Josey, S.D. (2009). Mineral deposits of northern Ontario, north of latitude 49° 30'; Ontario Geological Survey, Open File Report 6242, 69pp.

[178] Fowler, J.A., Grütter, H.S., Kong, J.M., and Wood, B.D. (2002) Diamond Exploration in Northern Ontario with reference to the Victor Kimberlite near Attawapiskat. Exploration and Mining Geology, 10 (1and 2), 67-75

[179] Fowler, J.A., Grütter, H.S., Kong, J.M., and Wood, B.D. (2002) Diamond Exploration in Northern Ontario with reference to the Victor Kimberlite near Attawapiskat. Exploration and Mining Geology, 10 (1and 2), 67-75.

[180] Webb K.J., Scott Smith B.H., Paul J.L. Hetman C.M. 2004. Geology of the Victor kimberlite, Attawapiskat, Northern Ontario, Canada: cross-cutting and nested craters. Proceedings of the 8th International Kimberlite Conference. Lithos 76, 29-50.

[181] Provincial Recording Ofice, MNDMF, personal communication, March 10, 2010.

[182] Atkinson, L.C., Keeping, P.G. and Wright, J.C. (2009). The economic challenges of dewatering at the Victor Diamond Mine in Northern Ontario, Canada. Proceedings of the International Mine Water Conference, Pretoria, South Africa, 19th – 23rd October 2009.

[183] AMEC. 2007. Victor Project – Mercury Update: Potential for Mercury Release from Peatlands, Available Data, and Monitoring Programs (AMEC May 28, 2007 letter report addressed to Lise-Aurore Lapalme (NRCan) and Carl Jorgensen (DFO).

[184] Webb K.J., Scott Smith B.H., Paul J.L. Hetman C.M. 2004. Geology of the Victor kimberlite, Attawapiskat, Northern Ontario, Canada: cross-cutting and nested craters. Proceedings of the 8th International Kimberlite Conference. Lithos 76, 29-50. Also see: http://www.debeerscanada.com/files_3/victor-mine.php (accessed 24 Feb, 2010).

[185] Stott, G.M. and Josey, S.D. (2009). Mineral deposits of northern Ontario, north of latitude 49° 30'; Ontario Geological Survey, Open File Report 6242, 69pp

[186] Stott, G.M. (2009). Exploration Reviews, Canada, Ring of Fire. SEG Newsletter, Number 77, April, 2009, 30-31.

[187] Breaks, F.W., Selway, J.B., Tindle, A.G. (2003). Fertile Peraluminous Granites and Related Rare-Element Mineralization in Pegmatites, Superior Province, Northwest and Northeast Ontario: Ontario Ministry of Northern Development and Mines, Ontario Geological Survey Open File Report OFR6099

[188] Stott, G.M. (2009). Exploration Reviews, Canada, Ring of Fire. SEG Newsletter, Number 77, April, 2009, 30-31.

[189] P and E Mining Consultants Inc. (2008). Technical Report and Preliminary Economic Assessment on the Eagle One Property, McFauld's lake area, James Bay Lowlands, Ontario, Latitude 52o45'N. Longitude 86o17'W for Noront Resources Ltd. 108 pp.

[190] Trip. L., Chevalier, P. and Smith J., (2000). The status of mercury in Canada, Report #2; A background report to the Commission for Environmental Cooperation, North American Task Force on Mercury, Environment Canada Transboundary Air Issues Branch, 72 pp.

[191] Rytuba, J.J. (2003). Mercury from mineral deposits and potential environmental impact, Environmental Geology 343, 326-338.

[192] Eckstrand and Hulbert, (2007). Magmatic nickel-copper-platinum group element deposits., in Goodfellow W.D., ed., Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 2-5-222).

[193] Steedman, R.J., J.M. Gunn and R.A. Ryder. 2004. Boreal Shield Waters: Models and Management Challenges. Boreal Shield Watersheds: Lake Trout Ecosystems in a Changing Environment, J.M. Gunn, R.J. Steedman and R.A. Ryder, Eds., Lewis Publishers, Boca Raton, FL, pp. 331-346.

[194] Bezys, R. (1990) Geology of the gypsum deposits of the Moose River Basin. Ontario Geological Survey, Open File Report 5728. Ontario Geological Survey (1996). Aggregate Resources Inventory Paper 160 56 pp. Kelly, R.I. (1996) High purity calcite and dolomite resources of Ontario. Ontario Ministry of Northern Development and Mines, Ontario Geological Survey, Open File Report 5954.

[195] Telford, P.G., Long, D.G.F., Norris, G., Zippi, P., and Griffiths, R. (1991) Mesozoic Geology and Lignite Potential of the Moose River Basin. Ontario Geological Survey, Open File Report 5777

[196] Admiral Bay Resources (2004). Press release Dec 6, 2004.

[197] Eugster W, Rouse WR, Pielke RA, McFadden JP, Baldocchi DD, Kittel TGF, Chapin FS, Liston GE, Vidale PL, Vaganov E, Chambers S (2000). Land-atmosphere energy exchange in Arctic tundra and boreal forest: Available data and feedbacks to climate. Global Change Biology 6, 84-115.

[198] Guillemette, F., Plamondon, A. P., Prevost, M., Levesque, D. 2005. Rainfall generated stormflow response to clearcutting a boreal forest: peak flow comparison with 50 world–wide basin studies. Journal of Hydrology 302, 137-153.

[199] Fredeen AL, Waughtal JD, Pypker TG (2007). When do replanted sub-boreal clearcuts become net sinks for CO2? Forest Ecology and Management 239, 210-216. Pypker TG, Fredeen AL (2002). Ecosystem CO2 flux over two growing seasons for a sub-boreal clearcut 5 and 6 years after harvest. Agricultural and Forest Meteorology 114, 15-30. Wirth C, Czimczik CI, Schulze ED (2002). Beyond annual budgets: Carbon flux at different temporal scales in fire-prone Siberian Scots pine forests. Tellus 54B, 611-630. Amiro BD, Barr AG, Black TA, Iwashita H, Kljun N, McCaughey JH, Morgenstern K, Murayama S, Nesic Z, Orchansky AL, Saigusa N (2006). Carbon, energy and water fluxes at mature and disturbed forest sites, Saskatchewan, Canada Agricultural and Forest Meteorolo205 Garcia E., and Carignan R. (1999) Impact of wildfire and clear-cutting in the boreal forest on methyl mercury in zooplankton. Can. J. Fish. Aquat. Sci. 56, 339–345. Garcia E., and Carignan R. (2000) Mercury concentrations in northern pike (Esox lucius) from boreal lakes with logged, burned, or undisturbed catchments. Can. J. Fish. Aquat. Sci. 57(S2), 129–135. Carignan, R., D'Arcy, P. and Lamontagne S. 2000. Comparative impacts of fire and forest harvesting on water quality in Boreal Shield lakes Can. J. Fish. Aquat. Sci. 57(S2), 105–117. Allen, E.W. Prepas, E.E. Gabos, S., Strachan, W.M.J. and Zhang W. (2005) Methyl mercury concentrations in macroinvertebrates and fish from burned and undisturbed lakes on the Boreal Plain. Can. J. Fish. Aquat. Sci. 62, 1963–1977.

[200] Garcia, E., R. Carignan and D.R.S. Lean. 2007. Seasonal and inter-annual variations in methyl mercury concentrations in zooplankton from boreal lakes impacted by deforestation or natural forest fires. Environmental Monitoring and Assessment 25: 476-482.

[201] Grigal, D. F. (2003) Mercury sequestration in forests and peatlands: a review. Journal of Environmental Quality 32, 393-405.

[202] Thorpe, H.C., Thomas, S.C., and Caspersen, J.P. (2008) Tree mortality following structural retention harvests is determined by skidding proximity. Ecological Applications 18, 1652-1663.

[203] Thompson,J.E. and W.A. Hutchison. 1987. Resource use by Native and non-Native hunters of the Ontario Hudson bay lowland. Ontario Ministry of Natural Resources, Toronto, Ontario.150 pp.

[204] Thompson,J.E. and W.A. Hutchison. 1987. Resource use by Native and non-Native hunters of the Ontario Hudson bay lowland. Ontario Ministry of Natural Resources, Toronto, Ontario.150 pp.; Berkes, F., George, P.J., Preston, R.J., Hughes, A, Turner, J., and B.D. Cummins. 1994. Wildlife harvesting and sustainable regional Native economy in the Hudson and James bay Lowland, Ontario. Arctic 47: 350-360.

[205] Stewart, D. B., and W. L. Lockhart. 2005. An overview of the Hudson Bay marine eco- system. Canadian Technical Reports of Fisheries and Aquatic Sciences 2586:487 p.

[206] Steedman, R.J., J.M. Gunn and R.A. Ryder. 2004. Boreal Shield waters: models and managemnt challenges. p. 331-346. In Gunn et. al. (ed.) Boreal Shield Watershed: Lake Trout Ecosystems in a Changing Environment. Lewis Publisher, CRC press.

[207] Morin, R., J. J. Dodson and G. Power. 1982. Life-history of anadromous cisco (*Coregonus artedii*), lake Whitefish (C. *clupeaformis*) and round Whitefish (*Prosopium cylindraceum*) populations of eastern James-Hudson Bay. Can. J. Fish. Aquat. Sci 39 : 958-967.

[208] W.L. Lockhart, G.A. Stern, G. Low, M. Hendzel, G. Boila, P. Roach, M.S. Evans, B.N. Billeck, J. DeLaronde, S. Friesen, K. Kidd, S. Atkins, D.C.G. Muir, M. Stoddart, G. Stephens, S. Stephenson, S. Harbicht, N. Snowshoe, B. Grey, S. Thompson and N. DeGraff. 2005. A history of total mercury in edible muscle of fish from lakes in northern Canada. Science of The Total Environment, Volumes 351-352, Pages 427-463. Marlene S. Evans, Derek Muir, W. Lyle Lockhart, Gary Stern, M. Ryan and Pat Roach. 2005. Persistent organic pollutants and metals in the freshwater biota of the Canadian Subarctic and Arctic: An overview. Science of The Total Environment Volumes 351-352, 1 December 2005, Pages 94-147.

[209] Research Resolutions and Consulting Ltd. 2001. An Economic Profile of Resource-based Tourism in Ontario, 2003. Report prepared for the Resource-based Tourism Unit, Tourism Branch, Ontario Ministry of Tourism and Recreation. (available online at *http://www.tourism.gov.on.ca/english/tourism/eco-profile-rbt2001-e.pdf*)

[210] Hunt, L. M., Haider, W., Boxall, P. C., & Englin, J. (2008). A method for estimating the economic contribution of resource-based tourism. Forestry Chronicle, 84, 172-180.

[211] Hunt, L. M., Boxall, P. C., Englin, J., & Haider, W. (2005). Forest harvesting, resource based tourism and remoteness: An analysis of northern Ontario's sport fishing tourism. *Canadian Journal of Forest Research*, 35, 401-409.

[212] Lemelin, R.H. (2005). Wildlife tourism at the edge of chaos: Complex interactions between humans and polar bears in Churchill, Manitoba. In F. Berkes, R. Huebert, H. Fast, M. Manseau and A Diduck (Eds.), Breaking ice: Renewable resource and ocean management in the Canadian North (pp. 183-202). Calgary, Alberta: University of Calgary Press.

[213] Ministry of Northern Development and Mines. 2007. Tourism Sector Fact Sheet. 4pp.

[214] Cole, David N. 1990a. Ecological impacts of wilderness recreation and their management. In: Hendee, John C.; Stankey, George H., and Lucas, Robert C. Wilderness Management (2nd Ed.). Golden, CO: North American Press: 425-466.

[215] Liddle, M.J. (1997) Recreation Ecology. London: Chapman & Hall. Kaufman, S.D., Snucins, E., Gunn, J.M., and Selinger, W. (2009). Impacts of road access on lake trout (Salvelinus namaycush) populations: regional scale effects of overexploitation and the introduction of smallmouth bass (Micropterus dolomieu). Canadian Journal of Fisheries and Aquatic Sciences 66, 212-223; Gunn, J.M., and Sein, R. (2000). Effects of forestry roads on reproductive habitat and exploitation of lake trout (Salvelinus namaycush) in three experimental lakes. Canadian Journal of Fisheries and Aquatic Sciences 57, 97-104.

[216] Marion, J. L., Cole, D. N., and Bratton, S. P. 1986. Exotic vegetation in Wilderness areas. Pages 114-120 in R.C. Lucas, editor. Proceedings of the National Wilderness Research Conference. General Technical Report INT-212. Intermountain Research Station, USDA Forest Service, Ogden, UT.

[217] For example, an assessment of campsite and trail footprint at Great Smoky Mountains National Park, 83% of which is recommended for and managed as wilderness, showed that 0.05 percent of the Park's total acreage was affected. Nevertheless, even when the impacted area is small, disturbance can be intensive in some locations and can damage rare or endangered species, and vegetation and soil in sensitive ecosystems. Furthermore, some environments with low resource recovery rates will require long periods to recover from even limited degradation; see Liddle, M.J. (1997) Recreation Ecology. London: Chapman & Hall. Noss, R.F., Cooperrider, A., 1994. Saving Nature's Legacy: Protecting and Restoring Biodiversity. Defenders of Wildlife and Island Press, Washington, DC, 416 pp.

[218] Gunn, J.M., and Sein, R. (2000). Effects of forestry roads on reproductive habitat and exploitation of lake trout (Salvelinus namaycush) in three experimental lakes. Canadian Journal of Fisheries and Aquatic Sciences 57, 97-104.

[219] Knight, R.L. and Cole, D.N. 1995. Factors that influence wildlife responses to recreationists. Pp 71-80 in Knight, R.L. and Gutzwiller, K.J. (eds). 1995. Wildlife and Recreationists: coexistence through management and research. Island Press, Washington DC, USA. Liddle, M.J. (1997) Recreation Ecology. London: Chapman & Hall.

[220] Researchers have used a model to estimate changes to prices charged by tourism operators within an area, if fly-in sites were converted to boat-accessible sites or into road accessible sites. They estimated that prices would drop by 34% and that revenue generation would decrease from $3.34 million per year for fly-in-accessible sites to $2.22 million for boat- or train-accessible sites and $1.63 million for road-accessible sites. See for example: Hunt, L. M., Boxall, P. C., Englin, J., & Haider, W. (2005). Forest harvesting, resource based tourism and remoteness: An analysis of northern Ontario's sport fishing tourism. Canadian Journal of Forest Research, 35, 401-409; and Hunt, L. M., Boxall, P. C., Englin, J., & Haider W. (2005). Remote tourism and forest management: A spatial hedonic analysis. Ecological Economics, 53, 101-113.

[221] Rich, C. & T. Longcore (2006): Ecological Consequences of Artificial Lighting. Island Press, Washington

[222] Longcore T., Rich C. 2004. Ecological light pollution. Front Ecol Environ 2: 191–198.
[223] Adams, W.M. (2006). "The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century." Report of the IUCN Renowned Thinkers Meeting, 29–31 January, 2006. Retrieved on: 2009-02-16. See also: 2005 World Summit Outcome Document, World Health Organization, 15 September 2005

[224] Hunter, Malcolm L., Jr. 2002. Fundamentals of Conservation Biology. Blackwell Science, Inc.

[225] Bill 191, Section 6

[226] Imhoff M.L., Bounoua L., Ricketts T., Loucks, C., Harriss R. 5 & Lawrence W.T. 2004. Global patterns in human consumption of net primary production. Nature 429, 870-873.

[227] Potapov P., Yaroshenko A., Turubanova, S., Dubinin M, Laestadius L., Thies C., Aksenov D., Egorov A., Yesipova Y., Glushkov I., Karpachevskiy M., Kostikova A., Manisha A., Tsybikova E., & Zhuravleva I. (2008). Mapping the world's intact forest landscapes by remote sensing. Ecology and Society 13, 51. [online] *URL: http://www.ecologyandsociety.org/vol13/iss2/art51/*

[228] Schmiegelow, F., S. Cumming, et al. (2006). Conservation beyond crisis management: A conservation-matrix model. A discussion paper for the Canadian BEACONs project. Edmonton, AB, University of Alberta, BEACONs Project: 7 pp. Schmiegelow, F.K.A., S.G. Cumming, K. Lisgo, S. Leroux, L. Anderson, and K. Krawchuk, M. et al. 2008. A science-based framework for identifying system-level benchmarks in boreal regions of Canada. Canadian BEACONs Project Report #5. 124 pp.

[229] Lindenmayer D., Hobbs R.J., Montague-Drake R., Alexandra J., Bennett A., Burgman M., Cale P., Calhoun A., Cramer V., Cullen P., Driscoll D., Fahrig L., Fischer J., Franklin J., Haila Y., Hunter M., Gibbons P., Lake S., Luck G., MacGregor C., McIntyre S., Mac Nally R., Manning A., Miller J., Mooney H., Noss R., Possingham H., Saunders D., Schmiegelow F., Scott M., Simberloff D., Sisk T., Tabor G., Walker B., Wiens J., Woinarski J. & Zavaleta E. (2008). A checklis for ecological management of landscapes for conservation. *Ecology Letters*, 11, 78-91.

[230] Walters C.J. & Holling C.S. (1990). Large-scale management experiments and learning by doing. *Ecology*, 71, 2060-2068.

[231] Grimm N.B., Gergel S.E., McDowell W.H., Boyer E.W., Dent C.L., Groffman P., Hart S.C., Harvey J., Johnston C., Mayorga E., McClain M.E. & Pinay G. (2003). Merging aquatic and terrestrial perspectives of nutrient biogeochemistry. Oecologia, 137, 485-501. Nel J.L., Roux D.J., Abell R., Ashton P.J., Cowling R.M., Higgins J.V., Thieme M. & Viers J.H. (2009). Progress and challenges in freshwater conservation planning. *Aquatic Conservation-Marine and Freshwater Ecosystems*, 19, 474-485.

[231] Duinker, P. N. and L.A. Greig. 2006. The impotence of cumulative effects assessment in Canada:

Ailments and ideas for redeployment. Environmental Management. 37: 153-161.

[233] See for example the Proposed Growth Plan for Northern Ontario, Oct. 2009

[234] Schmiegelow, F., S. Cumming, et al. (2006). Conservation beyond crisis management: A conservation-matrix model. A discussion paper for the Canadian BEACONs project. Edmonton, AB, University of Alberta, BEACONs Project: 7 pp.

[235] Venter O., Brodeur N.N., Nemiroff L., Belland B., Dolinsek I.J. & Grant J.W.A. (2006). Threats to endangered species in Canada. *Bioscience*, 56, 903-910.

[236] Freedman, B. and T. C. Hutchinson. 1980. Pollutant inputs from the atmosphere and accumulation in soils and vegetation near a nickel-copper smelter at Sudbury, Ontario, Canada. Can. J. Bot. 58(1): 108-132.

[237] Peter B. Moyle and Jack E. Williams, 1990. Biodiversity loss in the temperate zone: decline of the native fish fauna of California. Conservation Biology, Vol. 4, No. 3 (Sep., 1990), pp. 275-284.

[238] Soulé M.E., Estes J.A., Berger J. & Del Rio C.M. (2003). Ecological effectiveness: Conservation goals for interactive species. *Conservation Biology*, 17, 1238-1250.

[239] Cardinale B.J., Hillebrand H., & Charles D.F. (2006). Geographic patterns of diversity in streams are predicted by a multivariate model of disturbance and productivity. UC Santa Barbara: Retrieved from: http://www.escholarship.org/uc/item/51p6j5hg.

[240] Hunter, M.L. (1999). *Maintaining Biodiversity in Forest Ecosystems*. Cambrige University Press. Cambridge, U.K.

[241] Schaeffer D.J., Herricks E.E. & Kerster H.W. (1988). Ecosystem health .1. measuring ecosystem health. Environmental Management, 12, 446-455.

[242] Williams, W.T. (1980). Air pollution disease in the Californian forests: a base line for smog disease on ponderosa and Jeffery pines in the Sequoia and Los Padres National Forests, California. Environ. Sci. Technol. 14:179-182. Mann, L.K., S.B. McLaughlin and D.S. Shriner. 1980. Seasonal physiological responses of white pine under chronic air pollution stress. Environ. Exp. Bot. 20:99-105.

[243] Norten, S.A., Hansen, D.W., and Compana, R.J. (1980). The impact of acid precipitation and heavy metals on soils in relation to forest ecosystems. In. Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, U.S.D.A., Forest Service Tech. Rep. PSW-43, Berkley, Calif., pp 152-164.

[244] G. E. Likens, F. H. Bormann, R. S. Pierce, and W. A. Reiners. 1978. Recovery of a Deforested Ecosystem. Science 3 February 1978: Vol. 199. no. 4328, pp. 492 – 496. Weber, M.G. (1977). Nutrient redistribution following fire in tundra and forest-tundra. MSc. thesis, University of New Brunswick, Fredericton, N.B. 69 pp.

[245] Turner W.R., Oppenheimer M. & Wilcove D.S. (2009). A force to fight global warming. *Nature*, 462, 278-279.

[246] Locke, H. & Mackey, B. (2009). The nature of climate change: reunite international climate change mitigation efforts with biodiversity conservation and wilderness protection. *International Journal of Wilderness*, 15:1-8. Turner W.R., Oppenheimer M. & Wilcove D.S. (2009). A force to fight global warming. Nature, 462, 278-279.

[247] Willis, K.J. and Bhagwat, S.A. 2009. Biodiversity and climate change. Science 326:806-807; Heller, N.E. and Zavaleta, E.S. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation 142:14-32.

[248] Gunderson, L. H., C. S. Holling, and S. Light. 1995. Barriers and bridges to renewal of ecosystems and institutions. Columbia University Press, New York, New York, USA.

[249] Borchers, Jeffrey G. 2005. Accepting uncertainty, assessing risk: Decision quality in managing wildfire, forest resource values, and new technology Forest Ecology and Management, Volume 211, Issues 1-2, 6 June 2005, pp. 36-46.

[250] Borchers, Jeffrey G. 2005. Accepting uncertainty, assessing risk: Decision quality in managing wildfire, forest resource values, and new technology Forest Ecology and Management, Volume 211, Issues 1-2, 6 June 2005, pp. 36-46.

[251] The adaptive management system for the Tasmanian Wilderness World Heritage Area—linking management planning with effectiveness evaluation. Chapter 13 in Allan, C. and Stankey, G. (eds), Adaptive Environmental Management. A Practitioners Guide. Springer and CSIRO Publishing, 351p.

[252] See for example the River Guardians and Fisheries Guardians programs used in monitoring of the Voisey's Bay region and other areas in Newfoundland and Labrador.

[253] Peterson G.D., Cumming G.S. & Carpenter S.R. (2003). Scenario planning: a tool for conservation in an uncertain world. *Conservation Biology*, 17, 358-366.

[254] Groves, C. R. 2003. *Drafting a Conservation Blueprint: A Practitioner's Guide to Planning for Biodiversity*. Washington, DC: Island Press. Lindenmayer D., Hobbs R.J., Montague-Drake R., Alexandra J., Bennett A., Burgman M., Cale P., Calhoun A., Cramer V., Cullen P., Driscoll D., Fahrig L., Fischer J., Franklin J., Haila Y., Hunter M., Gibbons P., Lake S., Luck G., MacGregor C., McIntyre S., Mac Nally R., Manning A., Miller J., Mooney H., Noss R., Possingham H., Saunders D., Schmiegelow F., Scott M., Simberloff D., Sisk T., Tabor G., Walker B., Wiens J., Woinarski J. & Zavaleta E. (2008). A checklist for ecological management of landscapes for conservation. *Ecology Letters*, 11, 78-91.

[255] Leroux S.J., Schmiegelow F.K.A., Lessard R.B. & Cumming S.G. (2007). Minimum dynamic reserves: A framework for determining reserve size in ecosystems structured by large disturbances. *Biological Conservation*, 138, 464-473.

[256] Poiani K.A., Richter B.D., Anderson M.G. & Richter H.E. (2000). Biodiversity conservation at multiple scales: Functional sites, landscapes, and networks. *Bioscience*, 50, 133-146.

[257] Poiani K.A., Richter B.D., Anderson M.G. & Richter H.E. (2000). Biodiversity conservation at multiple scales: Functional sites, landscapes, and networks. *Bioscience*, 50, 133-146.

[258] Groves, C. R. 2003. Drafting a Conservation Blueprint: A Practitioner's Guide to Planning for Biodiversity. Washington, DC: Island Press. Margules C.R. & Pressey R.L. (2000). Systematic conservation planning. Nature, 405, 243-253. Noss R.F., Carroll C., Vance-Borland K. & Wuerthner G. (2002). A multicriteria assessment of the irreplaceability and vulnerability of sites in the Greater Yellowstone Ecosystem. Conservation Biology, 16, 895-908.

[259] In Canada, there is a well-established framework for identifying ecological units based on soil types and vegetation cover, and this provides a hierarchical system for stratifying landscapes based on terrestrial attributes. The Far North of Ontario comprises two discrete ecozones and numerous ecoprovinces, ecoregions and ecodistricts in a nested hierarchy, the boundaries of which may also cross adjacent jurisdictions (Manitoba and Québec), as well as areas farther south in Ontario.

[260] Much Ontario policy already recommends the use of watersheds as a basis for land use planning. The primary recommendation of a major 1993 multi-ministry (MOEE, MNR, OMAFRA and MMAH), multi-partner (AMO – Association of Municipalities of Ontario, ACAO – Association of Conservation Authorities of Ontario) land use planning series of documents recommended that "The primary boundary for an ecosystem approach to land use planning should be the watershed". Since that time, the use of the watershed context in the planning process has been consistently strengthened at all jurisdictional levels – including more recently in Justice O'Connor's Walkerton report. Important Ontario policy statements relating to this include: Land Use Planning on a Watershed Basis *http://www.ene.gov.on.ca/programs/3109e.htm*; Subwatershed Planning *http://www.mnr.gov.on.ca/MNR_E002320.pdf*; Integrating Water Management Objectives into Municipal Planning Documents. *http://www.mnr.gov.on.ca/MNR_E002321.pdf*; An Evaluation of Watershed Management in Ontario http://www.ene.gov.on.ca/programs/3513e.pdf; and Section 2.2 of the Provincial Policy Statement (PPS), which states: "Planning authorities shall protect, improve or restore the quality and quantity of water by using the watershed as the ecologically meaningful scale for planning." (MMAH, 2005)

[261] Fischer J. & Lindenmayer D.B. (2007). Landscape modification and habitat fragmentation: a synthesis. Global Ecology and Biogeography, 16, 265-280.

[262] Wilcove D.S., McLellan C.H., & Dobson A.P. (1986). Habitat fragmentation in the temperate zone. In Conservation Biology, ed. ME Soulé, pp. 237–56. Sunderland, MA: Sinauer.

[263] Andren H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat - a review. Oikos, 71, 355-366. Fahrig L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology Evolution and Systematics*, 34, 487-515. Fischer J. & Lindenmayer D.B. (2007). Landscape modification and habitat fragmentation: a synthesis. Global Ecology and Biogeography, 16, 265-280.

[264] Singleton, P.H., Gaines, W.L. & Lehmkuhl, J.F. (2002) Landscape permeability for large carnivores in Washington: a geographic information system weighted-distance and least-cost corridor assessment. USDA Forest Service, Research Paper PNW-RP-549.

[265] Ewers R.M. & Didham R.K. (2006). Confounding factors in the detection of species responses to habitat fragmentation. *Biological Reviews*, 81, 117-142.

[266] Hannon S.J. & Schmiegelow F.K.A. (2002). Corridors may not improve the conservation value of small reserves for most boreal birds. *Ecological Applications*, 12, 1457-1468.

[267] Folke C., Carpenter S., Walker B., Scheffer M., Elmqvist T., Gunderson L. & Holling C.S. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology Evolution and Systematics*, 35, 557-581.

[268] Groffman P., Baron J., Blett T., Gold A., Goodman I., Gunderson L., Levinson B., Palmer M., Paerl H., Peterson G., Poff N., Rejeski D., Reynolds J., Turner M., Weathers K. & Wiens J. (2006). Ecological thresholds: The key to successful environmental management or an important concept with no practical application? *Ecosystems*, 9, 1-13.

[269] Lindenmayer D., Hobbs R.J., Montague-Drake R., Alexandra J., Bennett A., Burgman M., Cale P., Calhoun A., Cramer V., Cullen P., Driscoll D., Fahrig L., Fischer J., Franklin J., Haila Y., Hunter M., Gibbons P., Lake S., Luck G., MacGregor C., McIntyre S., Mac Nally R., Manning A., Miller J., Mooney H., Noss R., Possingham H., Saunders D., Schmiegelow F., Scott M., Simberloff D., Sisk T., Tabor G., Walker B., Wiens J., Woinarski J. & Zavaleta E. (2008). A checklist for ecological management of landscapes for conservation. Ecology Letters, 11, 78-91. Zhang, J., Jorgensen, J., Beklioglu, S.E. & Ince, M. (2003). Hysteresis in vegetation shift – Lake Mogan prognoses. Ecol. Model., 164, 227–238. Rockstrom J., Steffen W., Noone K., Persson A., Chapin F.S., Lambin E.F., Lenton T.M., Scheffer M., Folke C., Schellnhuber H.J., Nykvist B., de Wit C.A., Hughes T., van der Leeuw S., Rodhe H., Sorlin S., Snyder P.K., Costanza R., Svedin U., Falkenmark M., Karlberg L., Corell R.W., Fabry V.J., Hansen J., Walker B., Liverman D., Richardson K., Crutzen P. & Foley J.A. (2009). A safe operating space for humanity. *Nature*, 461, 472-475.

[270] Groffman P., Baron J., Blett T., Gold A., Goodman I., Gunderson L., Levinson B., Palmer M., Paerl H., Peterson G., Poff N., Rejeski D., Reynolds J., Turner M., Weathers K. & Wiens J. (2006). Ecological thresholds: The key to successful environmental management or an important concept with no practical application? *Ecosystems*, 9, 1-13.

[271] Radford, J.Q., Bennett, A.F., Cheers, G.J., 2005. Landscape-level thresholds of habitat cover for woodland-dependent birds. Biol Conserv 124, 317-337

[272] Hargis C.D., Bissonette J.A. & Turner D.L. (1999). The influence of forest fragmentation and landscape pattern on American martens. *Journal of Applied Ecology*, 36, 157-172.

[273] Environment Canada 2008. *Scientific Review for the Identification of Critical Habitat for Woodland Caribou (Rangifer tarandus caribou), Boreal Population, in Canada*. August 2008. Ottawa: Environment

Canada.

[274] Mladenoff D.J., Sickley T.A., Haight R.G. & Wydeven A.P. (1995). A regional landscape analysis and prediction of favorable gray wolf habitat in the northern Great-Lakes region. *Conservation Biology*, 9, 279-294.

[275] Vors L.S., Schaefer J.A., Pond B.A., Rodgers A.R. & Patterson B.R. (2007). Woodland caribou extirpation and anthropogenic landscape disturbance in Ontario. *Journal of Wildlife Management*, 71, 1249-1256.

[276] Groffman P., Baron J., Blett T., Gold A., Goodman I., Gunderson L., Levinson B., Palmer M., Paerl H., Peterson G., Poff N., Rejeski D., Reynolds J., Turner M., Weathers K. & Wiens J. (2006). Ecological thresholds: The key to successful environmental management or an important concept with no practical application? *Ecosystems*, 9, 1-13.

[277] Thrush S.F., Halliday J., Hewitt J.E. & Lohrer A.M. (2008). The effects of habitat loss, fragmentation, and community homogenization on resilience in estuaries. *Ecological Applications*, 18, 12-21.

[278] Hunter M.L., Bean M.J., Lindenmayer D.B. & Wilcove D.S. (2009). Thresholds and the mismatch between environmental laws and ecosystems. Conservation Biology, 23, 1053-1055.

[279] Environment Canada 2008. *Scientific Review for the Identification of Critical Habitat for Woodland Caribou (Rangifer tarandus caribou), Boreal Population, in Canada*. August 2008. Ottawa: Environment Canada.

[280] Kaufman S.D., Snucins E., Gunn J.M. & Selinger W. (2009). Impacts of road access on lake trout (Salvelinus namaycush) populations: regional scale effects of overexploitation and the introduction of smallmouth bass (Micropterus dolomieu). *Canadian Journal of Fisheries and Aquatic Sciences*, 66, 212-223.

[281] Dudley, N. (Editor) (2008). *Guidelines for Applying Protected Area Management Categories*. Gland, Switzerland: IUCN. x + 86pp.

[282] Arcese P. & Sinclair A.R.E. (1997). The role of protected areas as ecological baselines. Journal of Wildlife Management, 61, 587-602. Lindenmayer, D.B., Franklin, J.F. (2002). Conserving Forest Biodiversity: A Comprehensive Multiscaled Approach. Island Press, Washington, 351 p.

[283] Leroux, S.J., Krawchuk, M.A., Schmiegelow, F.K.A., Cumming, S.G., Lisgo, K., Anderson, L.G. and M. Petkova. 2010. Global protected areas and IUCN designations: does the category match the condition? Biological Conservation 143(3):609-617.

[284] Leroux S.J., Schmiegelow F.K.A., Lessard R.B. & Cumming S.G. (2007). Minimum dynamic reserves: A framework for determining reserve size in ecosystems structured by large disturbances. Biological Conservation, 138, 464-473.

[285] Schmiegelow, F.K.A., S.G. Cumming, K. Lisgo, S. Leroux, L. Anderson, and K. Krawchuk, M. 2008. A science-based framework for identifying system-level benchmarks in boreal regions of Canada. Canadian BEACONs Project Report #5. 124 pp. L. Anderson, L. 2009. Quantitative Methods for Identifying Ecological Benchmarks in Canada's Boreal Forest. M.Sc. 119 pp

[286] Schmiegelow, F.K.A., S.G. Cumming, K. Lisgo, S. Leroux, L. Anderson, and K. Krawchuk, M. et al. 2008. A science-based framework for identifying system-level benchmarks in boreal regions of Canada. Canadian BEACONs Project Report #5. 124 pp.

[287] Woodley S., Middlemiss J. & Borg, K. (2008). Islands to networks - solution for nature conservation?. Paper Commissioned for *Canadian Parks for Tomorrow: 40th Anniversary Conference*, May 8 to 11, 2008, University of Calgary, Calgary, AB. *http://hdl.handle.net/1880/46880*.

[288] Woodley, S., Middlemiss, J. & Borg, K. "Islands to Networks - Solution for Nature Conservation?" Paper Commissioned for Canadian Parks for Tomorrow: 40th Anniversary Conference, May 8 to 11, 2008, University of Calgary, Calgary, AB. (*http://hdl.handle.net/1880/46880*)

[289] Turner W.R., Oppenheimer M. & Wilcove D.S. (2009). A force to fight global warming. *Nature*, 462, 278-279. TEEB (2009). Summary: Responding to the Value of Nature 2009. – The Economics of Ecosystems and Biodiversity for National and International Policy Makers. *http://www.teebweb.org/LinkClick.aspx?fileticket=I4Y2nqgliCg%3d&tabid=1278&language=en-US*.

[290] Hooper D.U., Chapin F.S., Ewel J.J., Hector A., Inchausti P., Lavorel S., Lawton J.H., Lodge D.M., Loreau M., Naeem S., Schmid B., Setala H., Symstad A.J., Vandermeer J. & Wardle D.A. (2005). Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. Ecological Monographs, 75, 3-35. Carpenter S.R. & Folke C. (2006). Ecology for transformation. *Trends in Ecology & Evolution*, 21, 309-315.

[291] Noss, R. F. and A. Y. Cooperrider. 1994. *Saving Nature's Legacy*. Island Press, Washington D.C. Margules C.R. & Pressey R.L. (2000). Systematic conservation planning. Nature, 405, 243-253. Redford K.H., Coppolillo P., Sanderson E.W., Da Fonseca G.A.B., Dinerstein E., Groves C., Mace G., Maginnis S., Mittermeier R.A., Noss R., Olson D., Robinson J.G., Vedder A. & Wright M. (2003). Mapping the conservation landscape. *Conservation Biology*, 17, 116-131.

[292] Lowe, W. H. and G. E. Likens. 2005. Moving headwater streams to the head of the class. BioScience 55:196–197.

[293] Gomi T., Sidle R.C. & Richardson J.S. (2002). Understanding processes and downstream linkages of headwater systems. *Bioscience*, 52, 905-916. Freeman, M. C., C. M. Pringle, and C. R. Jackson. 2007. Hydrologic connectivity and the contribution of stream headwaters to ecological integrity at regional and global scales. *Journal of the American Water Resources Association* 43(1): 5-14.

[294] Gomi T., Sidle R.C. & Richardson J.S. (2002). Understanding processes and downstream linkages of headwater systems. *Bioscience*, 52, 905-916. Wipfli M.S., Richardson J.S. & Naiman R.J. (2007). Ecological linkages between headwaters and downstream ecosystems: Transport of organic matter,

invertebrates, and wood down headwater channels. *Journal of the American Water Resources Association*, 43, 72-85.

[295] Meyer J.L., Strayer D.L., Wallace J.B., Eggert S.L., Helfman G.S. & Leonard N.E. (2007). The contribution of headwater streams to biodiversity in river networks. *Journal of the American Water Resources Association*, 43, 86-103.

[296] Gomi T., Sidle R.C. & Richardson J.S. (2002). Understanding processes and downstream linkages of headwater systems. Bioscience, 52, 905-916. Wipfli M.S., Richardson J.S. & Naiman R.J. (2007). Ecological linkages between headwaters and downstream ecosystems: Transport of organic matter, invertebrates, and wood down headwater channels. *Journal of the American Water Resources Association*, 43, 72-85.

[297] Meyer J.L., Strayer D.L., Wallace J.B., Eggert S.L., Helfman G.S. & Leonard N.E. (2007). The contribution of headwater streams to biodiversity in river networks. *Journal of the American Water Resources Association*, 43, 86-103.

[298] Noss R.F., Carroll C., Vance-Borland K. & Wuerthner G. (2002). A multicriteria assessment of the irreplaceability and vulnerability of sites in the Greater Yellowstone Ecosystem. *Conservation Biology*, 16, 895-908.

[299] Coppolillo, P., H. Gomez, F. Maisels, and R. Wallace. 2004. Selection criteria for suites of landscape species as a basis for site-based conservation. Biological Conservation 115:419–430.

[300] Sanderson E.W., Jaiteh M., Levy M.A., Redford K.H., Wannebo A.V. & Woolmer G. (2002). The human footprint and the last of the wild. *Bioscience*, 52, 891-904.

[301] Hooper D.U., Chapin F.S., Ewel J.J., Hector A., Inchausti P., Lavorel S., Lawton J.H., Lodge D.M., Loreau M., Naeem S., Schmid B., Setala H., Symstad A.J., Vandermeer J. & Wardle D.A. (2005). Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs*, 75, 3-35.

[302] Wilson K.A., Carwardine J. & Possingham H.P. (2009). Setting Conservation Priorities. In: *Year in Ecology and Conservation Biology 2009*, pp. 237-264.

[303] Gaston K.J. & Fuller R.A. (2008). Commonness, population depletion and conservation biology. *Trends in Ecology & Evolution*, 23, 14-19.

[304] Coppolillo, P., H. Gomez, F. Maisels, and R. Wallace. 2004. Selection criteria for suites of landscape species as a basis for site-based conservation. Biological Conservation 115:419–430.

[305] Simberloff D. (1995). Flagships, umbrellas, and keystones: Is single-species management passe in the landscape era? In: *Symposium on Conservation Biology and Landscape Ecology - the Scientific Basis of a National Biodiversity Conservation Strategy* Zurich, Switzerland, pp. 247-257. Soulé, M.E., Estes J.A., Berger J. & Del Rio C.M. (2003). Ecological effectiveness: Conservation goals for interactive species.

Conservation Biology, 17, 1238-1250.

[306] Lambeck R.J. (1997). Focal species: A multi-species umbrella for nature conservation. *Conservation Biology*, 11, 849-856.

[307] Lambeck R.J. (1997). Focal species: A multi-species umbrella for nature conservation. *Conservation Biology*, 11, 849-856.

[308] Lindenmayer D., Hobbs R.J., Montague-Drake R., Alexandra J., Bennett A., Burgman M., Cale P., Calhoun A., Cramer V., Cullen P., Driscoll D., Fahrig L., Fischer J., Franklin J., Haila Y., Hunter M., Gibbons P., Lake S., Luck G., MacGregor C., McIntyre S., Mac Nally R., Manning A., Miller J., Mooney H., Noss R., Possingham H., Saunders D., Schmiegelow F., Scott M., Simberloff D., Sisk T., Tabor G., Walker B., Wiens J., Woinarski J. & Zavaleta E. (2008). A checklist for ecological management of landscapes for conservation. *Ecology Letters*, 11, 78-91.

[309] Franklin J.F. & Lindenmayer D.B. (2009). Importance of matrix habitats in maintaining biological diversity. *Proceedings of the National Academy of Sciences of the United States of America*, 106, 349-350.

Far North Science Advisory Panel
Final Report

ISBN 978-1-4435-3540-3 (Print)
ISBN 978-1-4435-3541-0 (Web)